KEITHLEY

Model 595 Quasistatic CV Meter Instruction Manual

Contains Operating and Servicing Information

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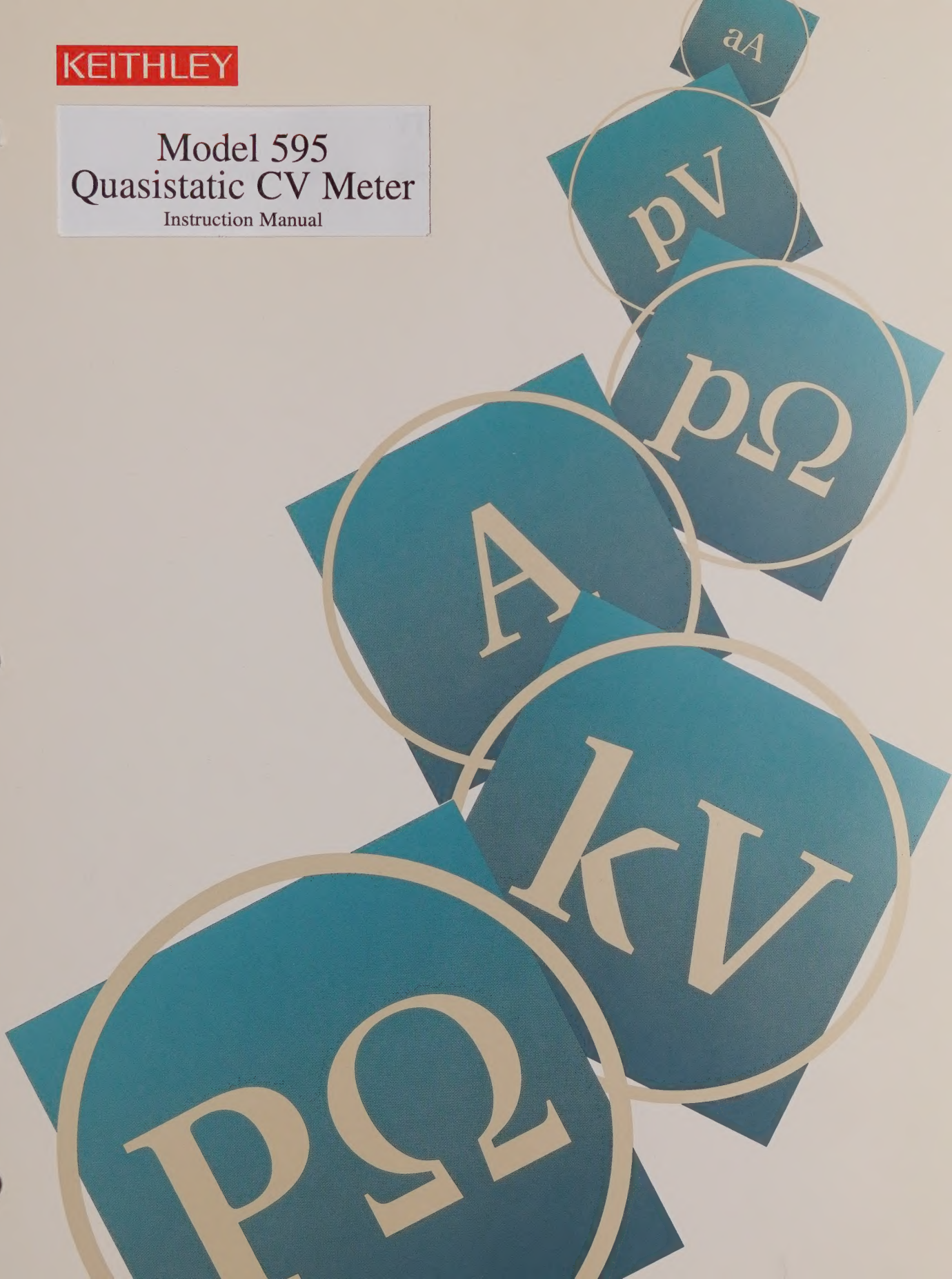
Model 595
Quasistatic CV Meter
Instruction Manual



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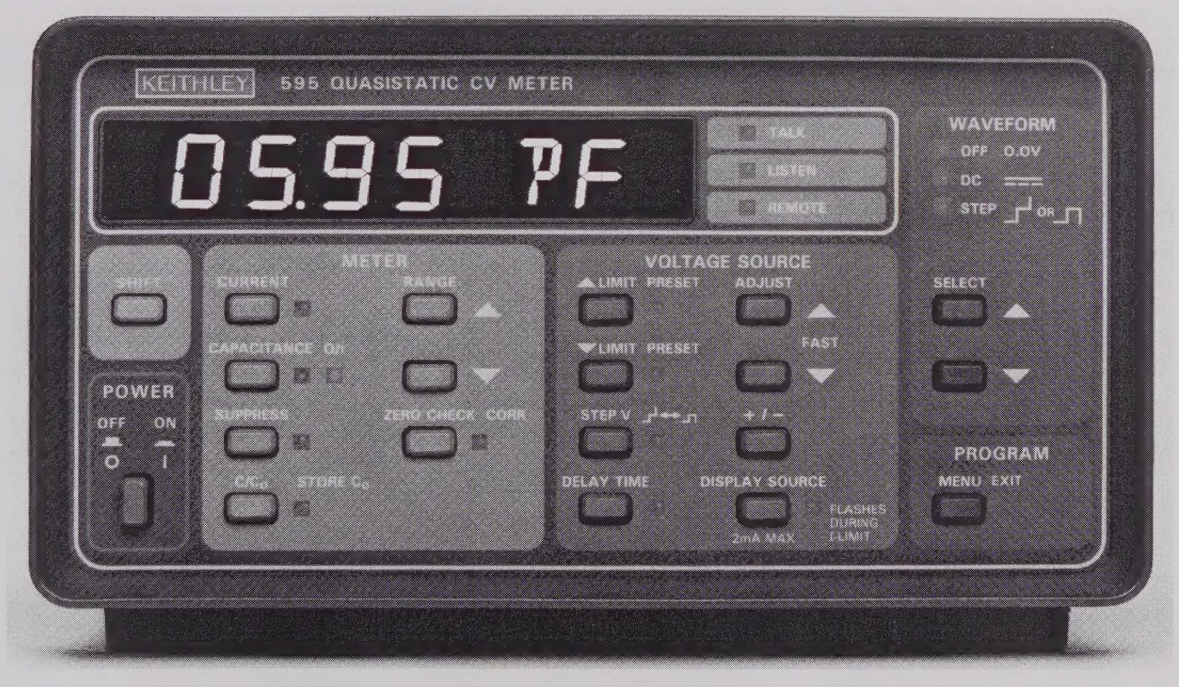

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Model 595 Quasistatic CV Meter
Instruction Manual

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Cleveland, Ohio, U.S.A.
November 1986, Second Printing
Document Number: 595-901-01 Rev. B

Safety Precautions

The following safety precautions should be observed before using this product and any associated instrumentation. Although some instruments and accessories would normally be used with non-hazardous voltages, there are situations where hazardous conditions may be present.

This product is intended for use by qualified personnel who recognize shock hazards and are familiar with the safety precautions required to avoid possible injury. Read the operating information carefully before using the product.

Exercise extreme caution when a shock hazard is present. Lethal voltage may be present on cable connector jacks or test fixtures. The American National Standards Institute (ANSI) states that a shock hazard exists when voltage levels greater than 30V RMS, 42.4V peak, or 60VDC are present. **A good safety practice is to expect that hazardous voltage is present in any unknown circuit before measuring.**

Before operating an instrument, make sure the line cord is connected to a properly grounded power receptacle. Inspect the connecting cables, test leads, and jumpers for possible wear, cracks, or breaks before each use.

For maximum safety, do not touch the product, test cables, or any other instruments while power is applied to the circuit under test. ALWAYS remove power from the entire test system and discharge any capacitors before: connecting or disconnecting cables or jumpers, installing or removing switching cards, or making internal changes, such as installing or removing jumpers.

Do not touch any object that could provide a current path to the common side of the circuit under test or power line (earth) ground. Always make measurements with dry hands while standing on a dry, insulated surface capable of withstanding the voltage being measured.

Do not exceed the maximum signal levels of the instruments and accessories, as defined in the specifications and operating information, and as shown on the instrument or test fixture rear panel, or switching card.

Do not connect switching cards directly to unlimited power circuits. They are intended to be used with impedance limited sources. NEVER connect switching cards directly to AC main. When connecting sources to switching cards, install protective devices to limit fault current and voltage to the card.

When fuses are used in a product, replace with same type and rating for continued protection against fire hazard.

Chassis connections must only be used as shield connections for measuring circuits, NOT as safety earth ground connections.

If you are using a test fixture, keep the lid closed while power is applied to the device under test. Safe operation requires the use of a lid interlock.

If a ⏚ screw is present on the test fixture, connect it to safety earth ground using #18 AWG or larger wire.

The ⚡ symbol on an instrument or accessory indicates that 1000V or more may be present on the terminals. Refer to the product manual for detailed operating information.

Instrumentation and accessories should not be connected to humans.

Maintenance should be performed by qualified service personnel. Before performing any maintenance, disconnect the line cord and all test cables.

SPECIFICATIONS

CAPACITANCE (C)

RANGE	RESOLUTION	ACCURACY* (1 Year) 18°-28°C ±(%rdg + counts)	MAXIMUM ALLOWABLE Q/t AT HALF RANGE C DELAY TIME = 0.07s STEP V = 0.10V
200 pF	10 fF	1.0 + 10	90.00 pA
2 nF	100 fF	0.8 + 2	0.900 nA
20 nF	1 pF	0.6 + 2	9.000 nA

*Exclusive of noise, for STEP V ≥0.05V and DELAY TIME ≤1 second. For other parameters, derate by (5mV/STEP V)×(DELAY TIME/1 second) in pF at 23°C. Double the derating for every 10°C rise in ambient temperature above 23°C.

MAXIMUM P-P NOISE (with supplied cable): ±(0.025% rdg + 0.075pF) × (100mV/STEP V) +2 counts with filter off, 0.1Hz to 10Hz.

Q/t: Measures non-equilibrium current and leakage current in the device under test during a capacitance measurement.

Display: 3 digits typical; resolution from 0.01fA to 0.01nA per count depending on range, STEP V, and DELAY TIME.

Measurement Time: DELAY TIME/8 or 0.044s, whichever is greater. Sampled at the end of each capacitance measurement.

Accuracy (1 Year, 18°-28°C): ±(1.0% rdg + 2 counts) exclusive of input bias current and noise.

TEMPERATURE COEFFICIENT (0°-18°C & 28°-40°C): ±(0.02% rdg + 0.1 count)/°C.

CURRENT (I)

RANGE	RESOLUTION	ACCURACY* (1 Year) 18°-28°C ±(%rdg + counts)	TEMPERATURE COEFFICIENT 0°-18°C & 28°-40°C ±(%rdg + counts)/°C
20 pA	1 fA	1.5 + 14	0.15 + 3
200 pA	10 fA	1.5 + 2	0.15 + 0.3
2 nA	100 fA	0.25 + 6	0.015 + 3
20 nA	1 pA	0.25 + 1	0.015 + 0.3
200 nA	10 pA	0.1 + 4	0.01 + 3
2 μA	100 pA	0.1 + 1	0.01 + 0.3
20 μA	1 nA	0.1 + 4	0.01 + 3
200 μA	10 nA	0.1 + 1	0.01 + 0.3

*When properly zeroed.

NMRR: 70dB on pA ranges, 60dB on nA and μA ranges, at 50 or 60Hz ±0.1%.

VOLTAGE SOURCE (V)

OUTPUT: −20.00V to 20.00V in 0.01V increments.

ACCURACY (1 Year, 18°-28°C): ±(0.2% + 10mV).

TEMPERATURE COEFFICIENT (0°-18°C & 28°-40°C): ±(0.005% + 200μV)/°C.

MAXIMUM OUTPUT CURRENT: ±2mA; active current limit at <4mA with annunciation.

SETTLING TIME: <3ms to rated accuracy.

NOISE: <(1ppm of output voltage + 100μV) p-p from 0.1 to 10Hz.

STEP Voltage: Selectable as 0.01V, 0.02V, 0.05V, or 0.10V (±2%). Polarity selectable + or −.

DELAY TIME: 0.07s to 199.99s in 0.01s increments (±0.05%).

STEP TIME: DELAY TIME plus 0.04s typical.

WAVEFORM: OFF: Outputs 0.0V ±0.01V.
DC: Outputs the programmed voltage.
STEP: Outputs changes in increments of STEP V from programmed voltage in either staircase or squarewave.

SQUAREWAVE: Repeatedly toggles between the programmed voltage and the programmed voltage plus STEP V, dwelling at each level for Step Time.

STAIRCASE: Repeatedly increments the output by STEP V until the upper or lower LIMIT is reached, dwelling at each level for Step Time.

ANALOG OUTPUTS

C, I OUTPUT LEVEL: 1V = 10,000 counts on ×1 gain; 1V = 1000 counts on ×10 gain.

V OUTPUT LEVEL: 1V = 10V on voltage source output.

MAXIMUM OUTPUT VOLTAGE: ±2V.

OUTPUT RESISTANCE: 1kΩ.

ACCURACY: ±(0.25% of displayed reading + 2mV).

RESPONSE TIME: Follows display.

ISOLATION: 30V peak from chassis or GUARD to ANALOG OUTPUT LO, which is connected to IEEE COMMON.

IEEE-488 BUS IMPLEMENTATION

MULTILINE COMMANDS: DCL, LLO, SDC, GET, GTL, UNT, UNL, SPE, SPD.

UNILINE COMMANDS: IFC, REN, EOI, SRQ, ATN.

INTERFACE FUNCTIONS: SH1, AH1, T5, TE0, L4, LE0, SR1, RL0, PP0, DC1, DT1, C28, E1.

PROGRAMMABLE PARAMETERS: Function, RANGE, ZERO CHECK, CORRect, SUPPRESS, C/C_o, STORE C_o, Voltage Source Parameters, WAVEFORM, Display Parameter, Filter, Trigger, Analog Output ×10, PEN LIFT, Capacitance Correction, Calibration, Self Test, Output Format, SRQ, Status, ASCII Terminator, EOI.

PLOTTER: Controls HP7470A plotter or equivalent using HPGL via IEEE-488 for real time plotting of C, Q/t, or I vs. V curves. Accessed by selecting Model 595 address 42 or 43. Talks to plotter on address 05. HPGL commands used are IN, IP, IW, PA, PD, PU, SC, SI, SP.

GENERAL

DISPLAY: 4½-digit numeric LEDs with appropriate decimal point and polarity indication. Signed 2-digit alphanumeric exponent.

UPDATE RATE: In I, one reading each Step Time.
In C, one reading each 2× Step Time.

OVERRANGE INDICATION: Display reads OL.

INPUT BIAS CURRENT (all functions): <5fA (5 × 10^{-15}A) at 23°C. Approximately doubles for every 10°C increase in ambient temperature above 23°C.

INPUT VOLTAGE BURDEN: <1mV.

MEASUREMENT SETTLING TIME: Within one reading except 2.5s (to 1% of step change) on pA ranges.

PROGRAMS: Provide front panel access to Filter, Trigger, Analog Output ×10, Corrected Capacitance, IEEE-488 address, Alpha or Numeric Exponent, plotter Y Hi Limit, Y Lo Limit, Grid, 50/60Hz selection, and Digital Calibration.

FILTER: Code	Readings Weighted	Typical White Noise Reduction	Typical Use
0	1	None	OFF
1	3	1.7	C or I vs. V measurements
2	9	2.5	C or I vs. V measurements
3	24	5	Steady C, I measurements

MAXIMUM INPUT: 30V peak, dc to 60Hz sine wave.

MAXIMUM COMMON MODE VOLTAGE: 30V maximum, dc to 60Hz sine wave.

INPUT CONNECTOR: Isolated BNC on rear panel.

OUTPUT CONNECTORS: Isolated BNCs on rear panel for VOLTAGE SOURCE OUTPUT, EXTERNAL TRIGGER, and METER COMPLETE. 5-way binding posts on rear panel for ANALOG OUTPUTs, PEN LIFT, GUARD, and Chassis.

EXTERNAL TRIGGER: TTL compatible EXTERNAL TRIGGER and METER COMPLETE.

ENVIRONMENT: Operating: 0° to 40°C, relative humidity 70% non-condensing up to 35°C. **Storage:** −25° to +65°C.

WARMUP: 2 hours to rated accuracy (see manual for recommended procedure).

POWER: 105-125V or 210-250V (internal switch selected), 50Hz to 60Hz, 15VA max. 90-110V and 180-220V version available upon request.

DIMENSIONS, WEIGHT: 127mm high × 216mm wide × 359mm deep (5 in. × 8½ in. × 14⅛ in.). Net weight 3.2kg (6 lbs., 14 oz.).

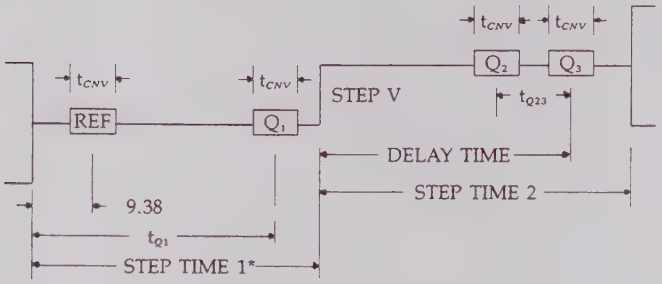
ACCESSORY SUPPLIED: Two Model 4801 Low Noise BNC Input Cables.

ACCESSORIES AVAILABLE:

Model 1019A: Universal Fixed Rack Mounting Kit
Model 1019S: Universal Slide Rack Mounting Kit
Model 4801: Low Noise Input Cable, 1.2m (4 ft.), BNC to BNC
Model 4803: Low Noise Cable Kit
Model 5955: Calibration Standards
Model 6104: Test Shield
Model 7007-1: Shielded IEEE-488 Digital Cable, 1m (3.3 ft.)
Model 7007-2: Shielded IEEE-488 Digital Cable, 2m (6.6 ft.)

595 SPECIFICATION CLARIFICATIONS

1) VOLTAGE SOURCE WAVEFORM: (Times shown are for 60Hz)



*Use STEP TIME 1 for each step while measuring current.

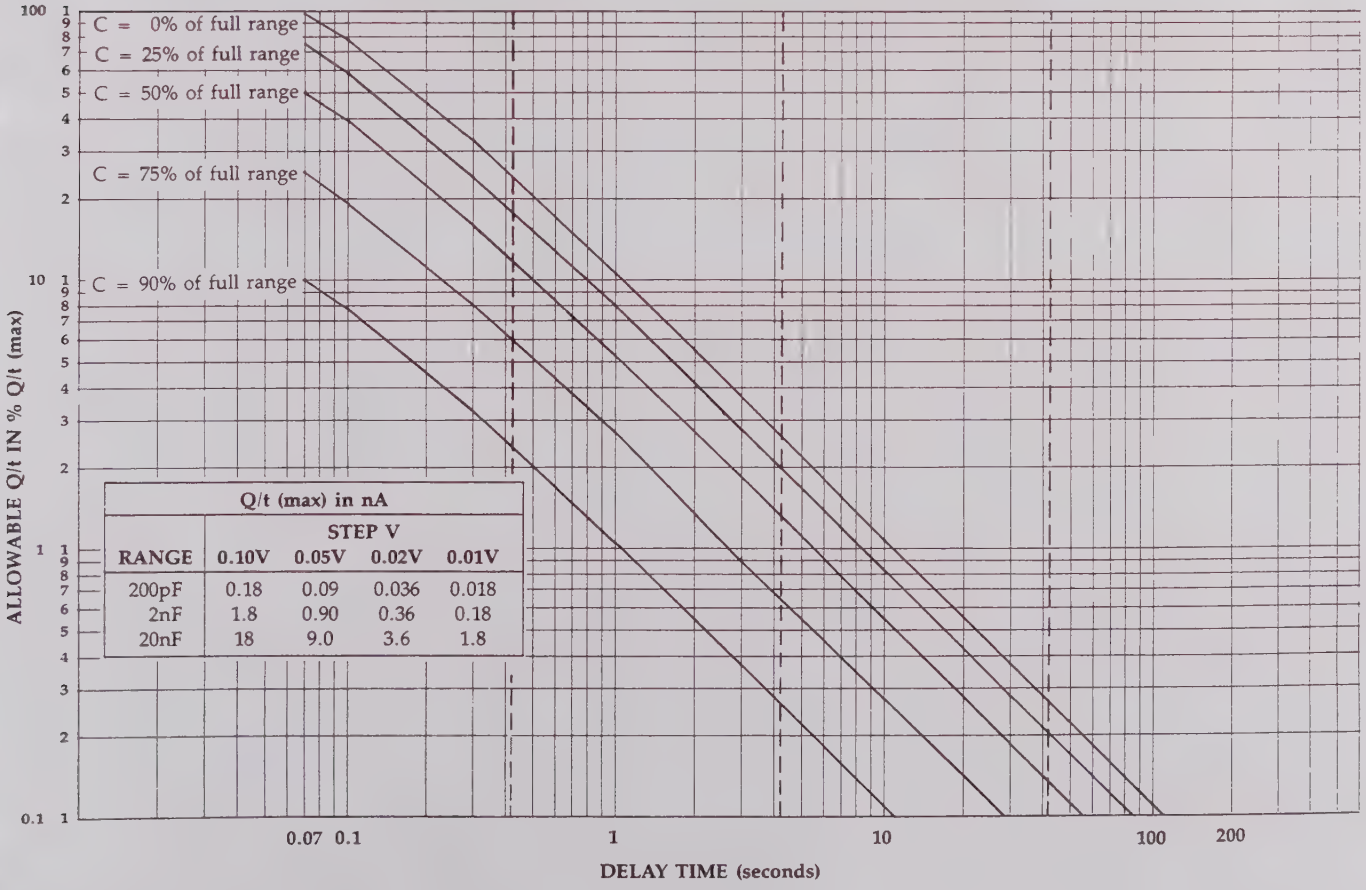
t_{DLY} = DELAY TIME, .05% stability
t_{Q1} = t_{DLY} + 3ms ; −0, +20ms
STEP TIME 1 = t_{Q1} + 31ms (60Hz), t_{Q1} + 33ms (50Hz)
Q/t Measurement Time (t_{Q23}) = t_{DLY} ÷ 8; 44ms minimum
STEP TIME 2 = t_{DLY} + 34ms; −0, +20ms (60Hz), t_{DLY} + 36ms; −0, +20ms (50Hz)
t_{CNV} = 16.67ms (60Hz), 20.00ms (50Hz)

2) MAXIMUM ALLOWABLE Q/t AT HALF RANGE C: The input dynamic range available for the Q/t measurement is reduced by the amount required to make the capacitance measurement (see chart below).

3) WHEN PROPERLY ZEROED: The instrument is zero CORRected on the 20pA range under the following conditions:
a. The instrument has warmed up for at least two hours.
b. Repeat as needed every 24 hours or if the ambient temperature changes by more than 1°C.

4) NMRR: For on-range normal mode sine wave inputs only. NMRR = 20 log [(peak-to-peak current input)/(peak-to-peak current display)] at 50 or 60Hz ±0.1%.

ALLOWABLE Q/t IN % OF Q/t (max) vs. DELAY TIME



Q/t (max) in nA				
	STEP V			
RANGE	0.10V	0.05V	0.02V	0.01V
200pF	0.18	0.09	0.036	0.018
2nF	1.8	0.90	0.36	0.18
20nF	18	9.0	3.6	1.8

— — — Indicates change of Q/t display resolution.

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SECTION 1
GENERAL INFORMATION

1.1 INTRODUCTION

The Keithley Model 595 Quasistatic CV Meter is a sensitive instrument designed to measure capacitance and current. The Model 595 uses a unique feedback charge method to stimulate and measure charge steps in the device under test, from which capacitance is determined. (A DC voltage is also available to make basic current measurements). This method of measuring capacitance is superior to the traditional "voltage ramp" method as it allows the user to distinguish between error currents and the stimulated signal charge. Correction of capacitance measurements for the effect of error currents is selectable and can be used to improve measurement accuracy. The Model 595 has a built-in ±20V source with four precision step voltage sources. The measuring range of the Model 595 is 0.01pF to 20nF for capacitance measurements and 1fA to 200μA for current measurements. A 4½ digit display and standard IEEE-488 interface give the user easy access to instrument data.

1.2 FEATURES

Some important Model 595 features include:

- Built-in Voltage Source—±20V @ 2mA voltage source with 10mV resolution.
- Bias Waveforms—DC, square wave, and staircase voltage bias waveforms allow the user to make stepped current or capacitance measurements, as well as DC current measurements.
- Voltage Steps—In ±10mV, 20mV, 50mV, and 100mV gradations at 0.07 to 199.99sec intervals in 0.01sec increments.
- Q/t Measurement—Q/t monitors current during capacitance measurement.
- Compensates for Error Currents—Selectable capacitance correction for leakage current errors.
- 4½ Digit Display—An easy-to-read front panel LED display includes a 4½ digit mantissa with selectable alphanumeric or scientific range annunciation.
- Zero Correct—A front panel zero correct control allows the user to cancel offsets internal to the Model 595.
- Reading Modifiers—Baseline suppression and C/C_0 normalization of readings.
- Standard IEEE-488 Interface—The built-in interface allows full bus operation of the Model 595.
- CV and IV Outputs—Built-in C, Q/t or I vs. V analog outputs (with automatic pen lift) or IEEE-488 digital plotter output.
- Digital Calibration—The instrument may be digitally calibrated from the front panel or over the IEEE-488 bus.

1.3 MANUAL ADDENDA

Information concerning improvements or changes to the instrument which occur after the printing of this manual will be found on an addendum sheet included with this manual. Please be sure that you read this information before attempting to operate or service your instrument.

1.4 SAFETY TERMS

The following safety terms are used in this manual:

The **WARNING** heading as used in this manual explains dangers that might result in personal injury or death. Always read the associated information very carefully before performing the indicated procedure.

The **CAUTION** heading used in this manual explains hazards that could damage the instrument. Such damage may invalidate the warranty.

1.5 UNPACKING AND INSPECTION

The Model 595 Quasistatic CV Meter was carefully inspected before shipment. Upon receiving the instrument, carefully unpack all items from the shipping carton and check for any obvious signs of physical damage that might have occurred during shipment. Report any damage to the shipping agent at once. Retain the original packing material in case reshipment becomes necessary.

The following items are included with every Model 595 shipment:

Model 595 Quasistatic CV Meter
Model 595 Instruction Manual
Model 4801 Low Noise Coax Cables with BNC Connectors (two)
Additional accessories as ordered.

If an additional instruction manual is required, order the manual package (Keithley Part Number 595-901-00). The manual package includes an instruction manual and all pertinent addenda.

1.6 REPACKING FOR SHIPMENT

Before shipping, the instrument should be carefully packed in its original packing material.

If the instrument is to be returned to Keithley Instruments for repair or calibration, include the following:

Write ATTENTION REPAIR DEPARTMENT on the shipping label.
Include the warranty status of the instrument.
Complete the service form at the back of this manual.

1.7 WARRANTY INFORMATION

Warranty information for your Model 595 may be found inside the front cover of this manual. Should you need to use the warranty, contact your Keithley representative or the factory for information on obtaining warranty service. Keithley Instruments, Inc. maintains service facilities in the United States, West Germany, Great Britain, France, the Netherlands, Switzerland, and Austria. Information concerning the operation, application, or service of your instrument may be obtained from the applications engineer at any of these locations.

1.8 ACCESSORIES

The following accessories are available to enhance Model 595 capabilities.

Model 1019A and 1019S Rack Mounting Kits—The Model 1019A is a fixed or stationary rack mounting kit with two front panels provided to enable either single or dual side-by-side mounting of the Model 595 or other similar Keithley instrument. The Model 1019S is a similar rack mounting kit with a sliding mount configuration.

Model 4801 Coax Input Cables—The Model 4801, two of which are included with every Model 595 shipment, are low noise coaxial cables, 1.2m (48 in.) in length, with male BNC connectors.

Model 4803 Low Noise Cable Kit—Kit includes 50 ft. of low noise coaxial cable, 10 male BNC connectors, and five female BNC chassis-mount connectors.

Model 6104 Test Shield—Model 6104 facilitates measurements with 2- or 3-terminal guarded connections. Provides electrostatic shielding, high isolation resistance, and easy connection to Model 595. Clips plug into banana jacks, allowing modified connections. Shield has BNC connector on one side, binding posts on the other. Useful when making current measurements with external voltage source.

Model 6105 Resistivity Chamber—Guarded test fixture for measuring volume and surface resistivities. Assures good electrostatic shielding and high insulation resistance.

Model 7007 Shielded IEEE-488 Cables—The Model 7007 cables are designed to connect the Model 595 to the IEEE-488 bus and are available in two versions. The Model 7007-1 is 1m (3.3 ft.) in length, and Model 7007-2 is 2m (6.6 ft.) in length. Cables have shielded connectors on each end.

Model 7051 BNC-to-BNC Cables—Available in two lengths. Model 7051-2 is 1.8m (2 ft.) in length, and Model 7051-5 is 1.5m (5 ft.) in length.

SECTION 2
GETTING STARTED

2.1 INTRODUCTION

The Model 595 can be controlled from the front panel or over the IEEE-488 bus. This section will acquaint the user with front panel operation. IEEE-488 bus operation is described in Section 4.

The following paragraphs will briefly describe the front panel buttons and their operation to help the user get started with the Model 595. Then rear panel descriptions and power-up information will be presented. Lastly, basic capacitance and current measurement examples will be discussed.

2.2 PREPARATION FOR USE

Once the instrument is unpacked, it must be connected to an appropriate power source as described below.

2.2.1 Line Power

The Model 595 is designed to operate from 105-125V or 210-250V power sources. A special power transformer may be installed for 90-110V and 195-235V ranges. The factory set range is marked on the rear panel of the instrument.

CAUTION

Do not attempt to operate the instrument on a supply voltage outside the indicated range, or instrument damage might occur.

2.2.2 Line Voltage Selection

The operating voltage of the instrument is internally selectable. Refer to Section 8 for the procedure to change or verify the line voltage setting.

2.2.3 Line Frequency

The Model 595 may be operated from either 50 or 60Hz power sources. The line frequency of the instrument must match the line frequency of the power source in order to meet measurement noise specifications. See Section 8 for details.

2.3 POWER UP PROCEDURE

2.3.1 Power Cord

Connect the female end of the power cord to the AC receptacle on the rear panel of the instrument. Connect the male end of the cord to a grounded AC outlet.

WARNING

The Model 595 is equipped with a 3-wire power cord that contains a separate ground wire and is designed to be used with grounded outlets. When proper connections are made, instrument chassis is connected to power line ground. Failure to use a grounded outlet may result in personal injury or death because of electric shock.

CAUTION

Be sure that the power line voltage agrees with the indicated range on the rear panel of the instrument. Failure to observe this precaution may result in instrument damage. If necessary, the line voltage may be changed as described in Section 8.

2.3.2 Defaults

Set POWER switch to its ON position. After briefly displaying "r.r." and "r.o.", the instrument will power up in the following configuration:

- 20nF CAPACITANCE range
- ZERO CHECK on
- VOLTAGE SOURCE = 0.00V
- WAVEFORM = 0.05V square wave
- DELAY TIME = 0.07sec
- VOLTAGE SOURCE LIMITS = ±20.00V

2.3.3 RAM and ROM Test Messages

Both RAM and ROM are automatically tested as part of the power up procedure. During normal power-up, "r.r." and "r.o." will briefly appear while memory is being tested. If a memory error occurs, the "r.r." or "r.o." message will remain on the display.

If the instrument was not able to read the stored calibration constants and configuration, the decimal points in the two exponent digits will flash.

If such errors occur, the instrument may be partially or completely inoperative. Refer to Section 8 for more complete details.

NOTE

If the instrument is still under warranty (less than one year from the date of shipment), and problems develop, it should be returned to Keithley Instruments for repair. See paragraph 1.6 for details on returning the instrument.

2.4 GENERAL DISPLAY MESSAGES

The Model 595 has a display made up of a 4½ digit signed mantissa as well as a two digit alphanumeric exponent. Messages are occasionally seen on the display to indicate instrument status or errors in operation. These display messages are listed in Table 2-1.

2.5 INSTRUMENT FAMILIARIZATION

The following figures, brief feature descriptions, and measurement examples will acquaint the Model 595 user with basic front and rear panel operation. For more in-depth information, see Section 3.

WARNING

The maximum common-mode input voltage (the voltage between input low and chassis ground) is 30V peak. Exceeding this value may create a shock hazard.

CAUTION

The maximum voltage between input high and input low is 30V peak. Exceeding this value may cause damage to the instrument. Current inputs that exceed 3mA may be erroneously displayed as an on-scale reading.

Table 2-1. Display Messages

Message	Description
OFF	Voltage source is OFF (0.00V ± 0.01V) and Model 595 is set to measure capacitance.
dc	Voltage source is set to DC waveform and Model 595 is set to measure capacitance.
A1	Software revision level; displayed as part of diagnostics.
P.-S P.-0 P.-C	Troubleshooting diagnostics (see Section 8). Phases: signal, zero and reference.
OL	Overload (overrange input applied); −OL for negative value.
bErr	Bus Error: Instrument programmed while not in remote; or illegal command or command option sent.*
nErr	Number Error: Calibration, voltage source, waveform parameter, or program value beyond allowable range.*
tErr	Trigger Overrun Error: Instrument triggered during a measurement conversion.*
r.r.	RAM Test Failure: ON while RAM memory is being tested. If message remains, the test failed.
r.0.	ROM Test Failure: ON while ROM memory is being tested. If message remains, the test failed.
▪.▪	Flashing Decimal Points in Exponents: Power-up calibration constants are not in use (due to nonvolatile memory error on power-up or calibration adjustment without storage).
▪.▪	Decimal Points Turned On in Exponent: Calibration program is in use.
trIG	The Model 595 is waiting for a trigger (bus, external, or SHIFT, then +/− button).

*See Section 4 for more information about IEEE-488 operation messages

2.5.1 Model 595 Front Panel

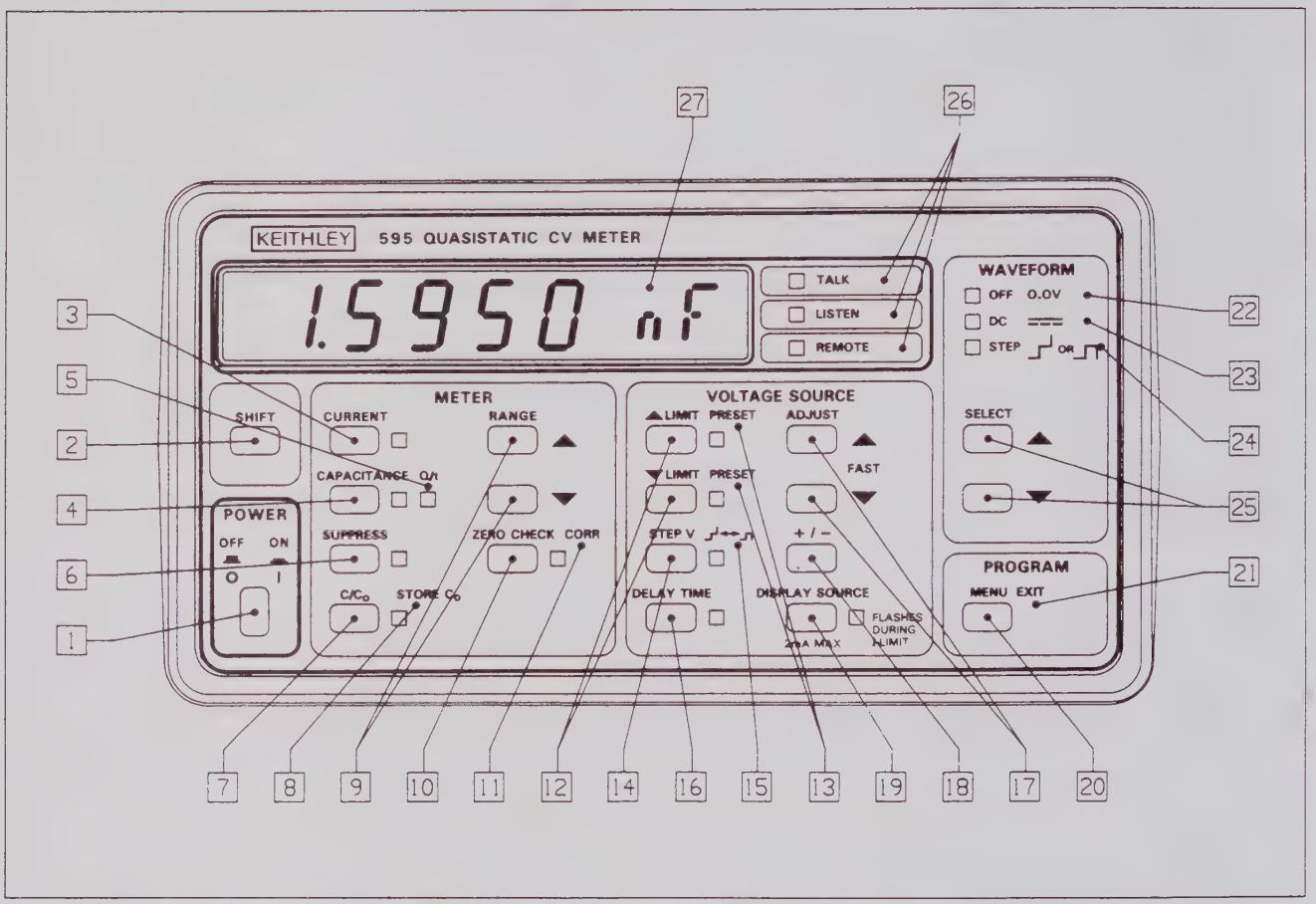


Figure 2-1. Model 595 Front Panel

All front panel controls except POWER are momentary contact switches. Many control buttons include an annunciator light to indicate the selected function. Some buttons have a secondary function that may be entered by pressing first SHIFT then the desired button. All such secondary functions are marked in yellow as is the SHIFT button. The controls are color-coded into functional groups for ease of operation.

1 **POWER**—AC POWER switch turns unit on or off.

2 **SHIFT**—Enables access to secondary features (highlighted in yellow).

METER BLOCK

3 **CURRENT**—Configures the Model 595 to measure current from 1fA to 200μA.

4 **CAPACITANCE**—Configures the Model 595 to measure capacitance from .01pF to 20nF.

5 **(SHIFT) Q/t**—CAPACITANCE display modifier. Displays current, which is measured at the end of each capacitance measurement.

6 **SUPPRESS**—Makes measurements relative to a stored baseline reading. Next reading is saved and will be subtracted from all subsequent readings. Applies only to current or capacitance measurements (not Q/t).

7 **C/C_0**—Divides all readings by a user-stored C_0 value. Applies only to capacitance readings (not Q/t or I).

8 **(SHIFT) STORE C_0**—Saves next reading as the C_0 value for C/C_0.

9 **RANGE**—Increments or decrements range (sensitivity). Three capacitance ranges and eight current ranges.

10 **ZERO CHECK**—Used as a standby condition. No readings can be taken when enabled.

11 **(SHIFT) CORRect**—Cancels the effects of internal offset voltage by storing a value which is scaled to cancel the offset on any range. Best when applied on 20pA range.

VOLTAGE SOURCE BLOCK

12 **▲ or ▼ LIMIT**—Displays VOLTAGE SOURCE adjustment LIMITs.

13 **(SHIFT) PRESET**—Quickly sets VOLTAGE SOURCE to the upper or lower LIMIT.

14 **STEP V**—Displays voltage step size (±.01, .02, .05, .10V)

15 **(SHIFT)** ⌐¬ —Toggles voltage step waveform between staircase and square wave.

16 **DELAY TIME**—Displays voltage step-to-measurement time.

17 **ADJUST ▲ or ▼**—Used to modify VOLTAGE SOURCE parameters (LIMITs, STEP V, DELAY TIME, and SOURCE voltage) and PROGRAM parameters. Press SHIFT, then FAST for a faster rate.

18 +/− —Toggles the sign of displayed STEP V or VOLTAGE SOURCE value. Press SHIFT, +/− to trigger a reading from front panel.

19 **DISPLAY SOURCE**—Shows VOLTAGE SOURCE value. Corresponding LED flashes when current limit of 2mA has been exceeded.

PROGRAM BLOCK

20 **MENU**—Accesses front panel programs: FREQUENCY, CALIBRATION, FILTER, TRIGGER, ANALOG OUTPUT, CORRECTED CAPACITANCE, IEEE-488 ADDRESS, DISPLAY. Accesses plotter parameters: GRID, Y HI, Y LO.

21 **(SHIFT) EXIT**—Leaves PROGRAM MENU.

WAVEFORM BLOCK

22 **OFF**—VOLTAGE SOURCE is 0.00 ± .01V.

23 **DC**—Unit sourcing DC voltage.

24 **STEP**—VOLTAGE SOURCE outputs either a staircase or square wave.

25 **SELECT ▲ or ▼**—Used to select voltage source output waveform.

26 **IEEE-488 BUS INDICATORS**—REMOTE, TALK and LISTEN represent interface status of Model 595.

27 **DISPLAY**—4½ digit signed mantissa with two-digit alphanumeric exponent.

2.5.2 Model 595 Rear Panel

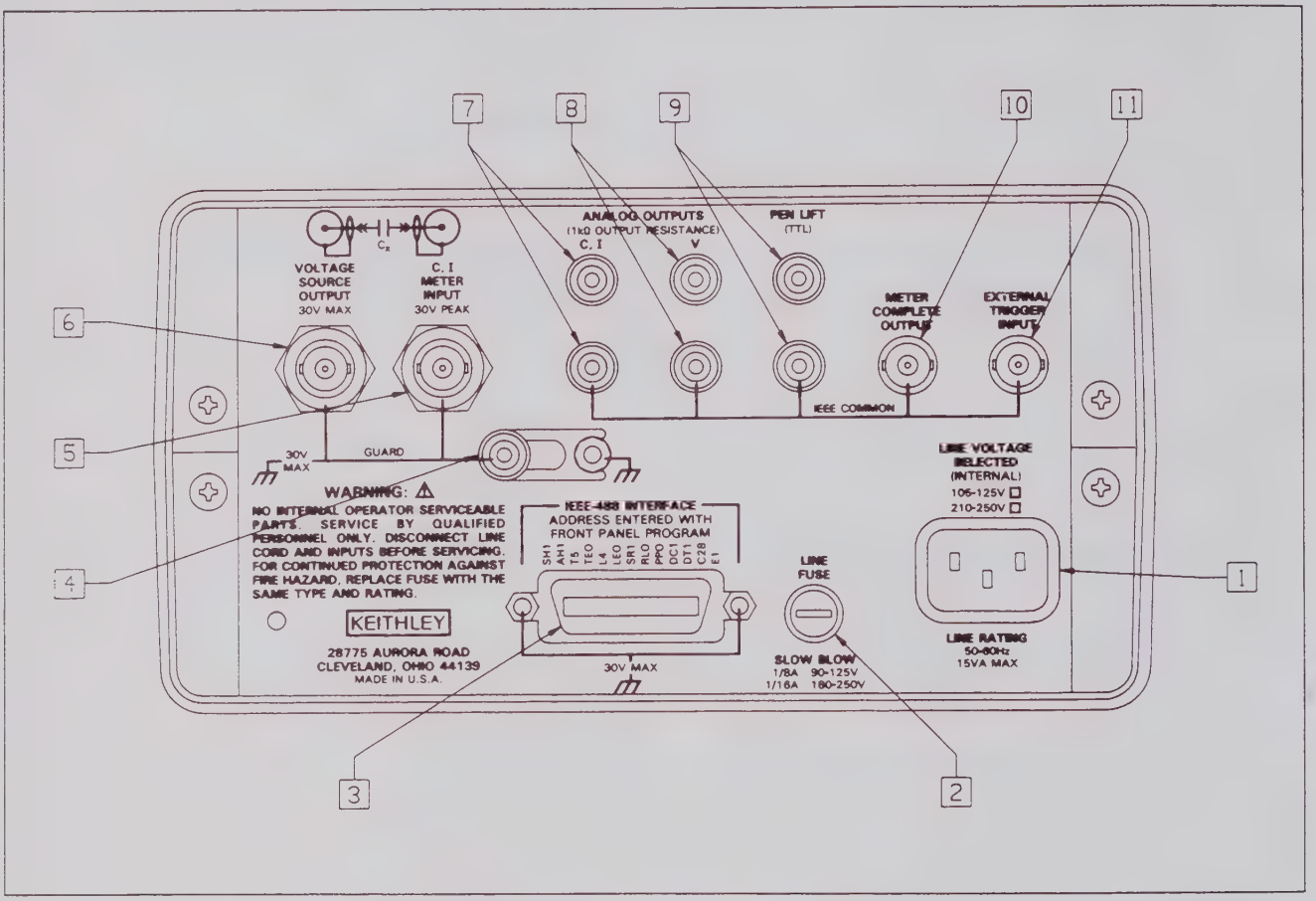


Figure 2-2. Model 595 Rear Panel

The rear panel of the Model 595 is illustrated in Figure 2-2.

1 **AC RECEPTACLE**—Connects to three-wire line cord.

2 **LINE FUSE**—Provides protection on the AC power line input.

3 **IEEE-488**—Connects the instrument to the IEEE-488 bus. IEEE-488 interface functions are marked above the connector.

4 **GUARD**—Provides binding post connection for shields or the LO terminal of an external voltage supply.

5 **C, I METER INPUT**—Teflon-insulated BNC. Inner conductor is input HI, outer conductor is GUARD.

6 **VOLTAGE SOURCE OUTPUT**—Isolated BNC connector. Inner conductor is output HI, outer conductor is GUARD. Voltage is sourced from this output to bias devices when making current or capacitance measurements. Referenced to GUARD.

7 **C, I ANALOG OUTPUT**—5-way binding posts that correspond to meter display (C, Q/t or I). Referenced to IEEE common.

8 **V ANALOG OUTPUT**—5-way binding posts that correspond to voltage at which C, Q/t, or I measurement was taken. Referenced to IEEE common.

9 **PEN LIFT**—Two 5-way binding posts; pen lift and IEEE common. Normally a TTL high output; TTL low during a staircase waveform. Minimizes recorder pen blotting.

10 **METER COMPLETE OUTPUT**—Isolated BNC connector provides negative going TTL output pulse after a reading is completed. Referenced to IEEE common.

11 **EXTERNAL TRIGGER INPUT**—Isolated BNC connector. Negative edge triggered, TTL level. Referenced to IEEE common.

2.5.3 Test Connections for Capacitance and Current Measurements

The Model 595 is supplied with two Model 4801 Low Noise BNC Cables. Use these cables or similar low noise cables when making measurements with the Model 595.

Most capacitance measurements can be made through one of the test setups illustrated in Figure 2-3. A semiconductor wafer in a "chuck and probe" apparatus is shown in Figure 2-3A, a packaged capacitor in a test box is shown in Figure 2-3B, and a setup with an external voltage source is shown in Figure 2-3C.

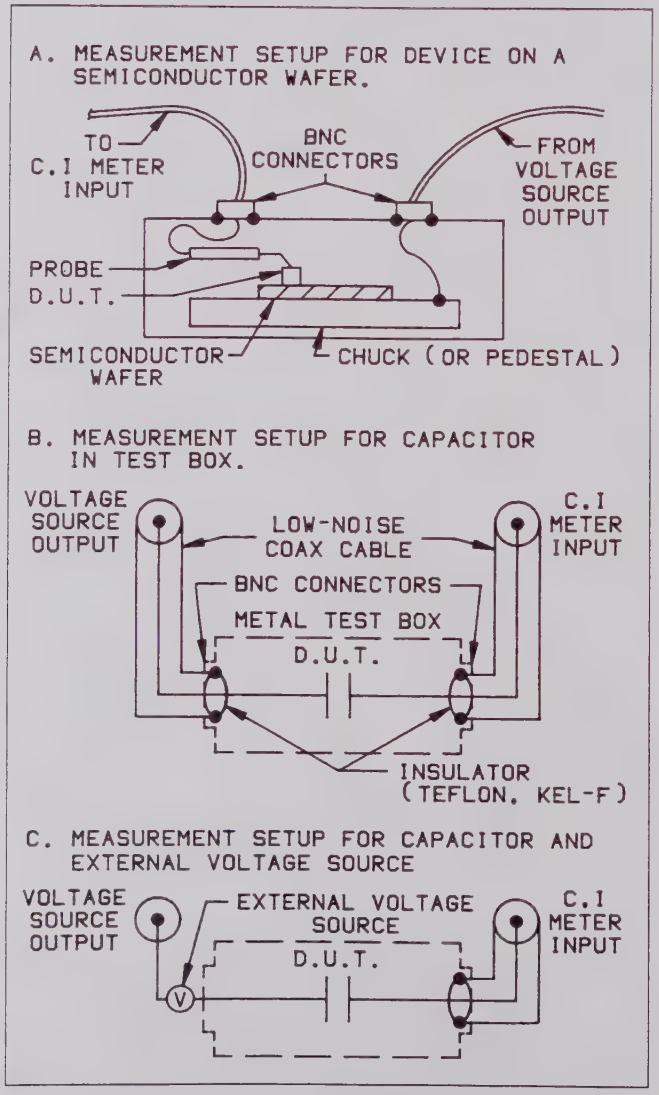


Figure 2-3. Typical Capacitance Measurement Connections

Refer to Figure 2-4A and 2-4B to see how to make current measurement connections. If a voltage source is used (to make resistance measurements, for example), see Figure 2-4 for connections. Use Figure 2-4A with an external voltage source and Figure 2-4B for connections with the Model 595's voltage source.

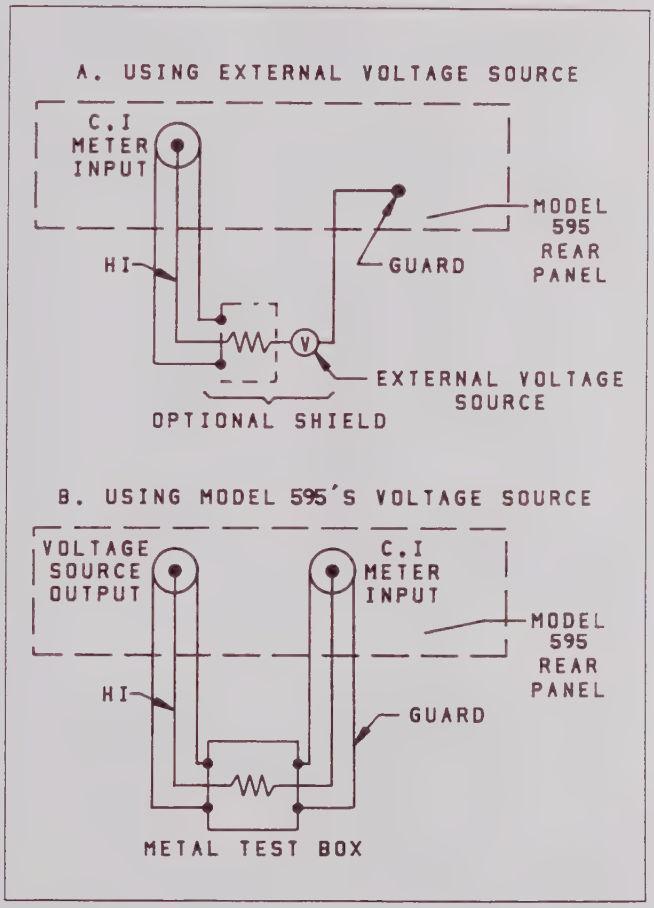


Figure 2-4. Typical Current Measurement Connections

Use the above figures to make rough measurement connections when following the examples described in paragraphs 2.5.4 through 2.5.7. Refer to paragraph 3.2 for more details on test connections.

2.5.4 Capacitance Example

The following is an example capacitance measurement to aquaint the user with typical measurement techniques. In this particular example, the device under test (D.U.T.) has a value of about 500pF.

The initial measurement configuration is power OFF, with connections as described in paragraph 2.5.3. The circuit is broken at the capacitor under test (i.e., the probe is lifted from the wafer).

Follow the steps outlined below to make a capacitance measurement. The first column indicates what button should be pressed; the second column shows what will be displayed on the Model 595, and the last column describes the results of the action taken.

Button Press	Display		Remarks
1. POWER	r.r. r.o. 0.000	 nF	Memory test (RAM) Memory test (ROM) 20nF capacitance range, ZERO CHECK on, square wave.
2. ZERO CHECK	0.001*	nF	ZERO CHECK off, measuring stray capacitance of fixture.
3. RANGE ▼	.0012*	nF	Go to range of desired resolution (D.U.T. will be about 500pF).
4. SUPPRESS	.0000	nF	SUPPRESS on, stray value will be subtracted from all readings.
5. ZERO CHECK	.0000	nF	ZERO CHECK on while connecting device.
6. (Connect capacitance in fixture)	.4562*	nF	Display is value of D.U.T. (minus fixture strays).
7. ZERO CHECK			ZERO CHECK off to resume measurement.
8. SHIFT, then STORE C_0	 .4562*	nF nF	 This value is stored as C_0 for normalization of capacitance.
9. C/C_0	1.0000*		The measured capacitance is normalized to C_0.
10. SHIFT, then Q/t	.0000*	nA	The magnitude of current through the D.U.T. at the time of each capacitance measurement (i.e., after delay time). Note: suppress and C_0 apply only to the capacitance measurement, not to Q/t.
11. CAPACITANCE*	1.0000*		Return to normalized capacitance display.
12. C/C_0	.4562*	nF	C/C_0 off.

* This value depends on the capacitor under test, any strays present, etc.

2.5.5 CV Example

Now that the user is acquainted with making basic capacitance measurements, the following example will illustrate the use of the voltage source to generate a staircase waveform while measuring capacitance.

The power up measurement configuration is identical to that of the previous example. Note that the device is disconnected at the box on the voltage source side.

Button Press	Display		Remarks
1. POWER	r.r.		Memory test (RAM)
	r.o.		Memory test (ROM)
	0.000	nF	20nF capacitance range, ZERO CHECK on, square wave.
CONFIGURE VOLTAGE SOURCE			
2. SELECT ▲	.dc	nF	Select DC (turns off STEP WAVEFORM). Capacitance not measured when voltage source set to DC.
3. ▲ LIMIT	20.00	V	Voltage source upper LIMIT (20V) displayed.
4. ADJUST ▼ (hold)	04.00	V	Adjust voltage source upper LIMIT to 4V. (Press SHIFT, then ADJUST for coarse adjustment)
5. ▼ LIMIT	−20.00	V	Voltage source lower LIMIT (−20V) displayed.
6. ADJUST ▲ (hold)	−01.00	V	Adjust voltage source lower LIMIT to −1V. (Press SHIFT, then ADJUST for coarse adjustment)
7. STEP V	00.05	SQ	Display present STEP magnitude and STEP type (square wave).
8. SHIFT, then STEP V	00.05	ST	Change STEP type to staircase.
9. ADJUST ▲	00.10	ST	Adjust STEP voltage to .1V.
10. DELAY TIME	00.07	S	Display present DELAY TIME (0.07 seconds).
11. ADJUST ▲ (hold)	00.50	S	Adjust DELAY TIME to 0.5 seconds.
12. DISPLAY SOURCE	00.00	V	Display present voltage source setting (0.00V).
13. ADJUST ▼ (hold)	−01.00	V	Adjust voltage source to lower LIMIT. (note that −1V is the limit of adjustment as set in step 6 above)
STAIRCASE OPERATION			
14. SELECT ▼	XX.XX	V	Select STEP waveform (set to staircase in step 8), observe that source steps are 0.1V. Source stops at upper LIMIT (4V) and waveform becomes DC.
15. STEP V	00.10	ST	Display STEP voltage.
16. +/−	−00.10	ST	Change STEP direction.
17. DISPLAY SOURCE	04.00	V	Display voltage source output.
18. SELECT ▼	XX.XX	V	Select and start staircase.
19.	−01.00	V	Source stops at −1V and waveform becomes DC.
PAUSING STAIRCASE WAVEFORM			
Use SELECT ▼ to start staircase, SELECT ▲ to pause, and SELECT ▼ to continue.			

Button Press	Display		Remarks
MEASURE CV			
20. Set WAVEFORM to DC, STEP V to +.10V. Described above.			
(CONNECT CAPACITANCE IN FIXTURE)			
21. SHIFT, then ▼ LIMIT (PRESET)	−01.00	V	Display and PRESET voltage source to value of ▼ LIMIT.
22. DISPLAY SOURCE	.dc	nF	Return display to meter.
23. ZERO CHECK	.dc	nF	Turn off ZERO CHECK.
24. SELECT ▼	XX.XXX	nF	Capacitance readings during staircase; "dc" appears when staircase reaches upper LIMIT.
	.dc	nF	

NOTE: SUPPRESS, C/C_0, STORE C_0, and Q/t may be selected or cancelled, and voltage source parameters may be monitored, without affecting the staircase waveform. A parameter change, however, will "pause" the staircase (i.e., the waveform will change to DC).

2.5.6 Measuring Current: An Example

The following is an example of a typical current measurement. This example uses a 1MΩ resistor in a test box. See Figure 2-4 for measurement connections. The voltage source is set to 1V to cause 1μA input current to flow (I = 1V/1MΩ).

The initial measurement configuration is POWER off, with input cables attached to the Model 595. The input circuit is temporarily disconnected at the test box, on the voltage source output side.

Button Press	Display		Remarks
1. POWER	r.r.		Memory test (RAM)
	r.o.		Memory test (ROM)
	0.000	nF	20nF capacitance range, ZERO CHECK on, square wave.
2. CURRENT	−.0002*	nA	Place unit in CURRENT function.
3. RANGE ▼ (press twice)	−0.002*	pA	Set unit to 20pA range.
4. SHIFT, then CORR	0.000	pA	Corrects for internal offsets.
5. RANGE ▲	.0000	μA	Go to RANGE of desired resolution (press five times for this example).
(CONNECT RESISTOR)			
6. SELECT ▲	.0000	μA	Select DC WAVEFORM.
7. DISPLAY SOURCE	00.00	V	Displays voltage sourced.
8. ADJUST ▲	01.00	V	Adjust voltage source to 1V out.
9. DISPLAY SOURCE	.0000	μA	Return unit to meter display.
10. ZERO CHECK	.9835*	μA	Read value from display.

* This value depends on the resistor under test, stray currents, etc.

Variation: Also try using SUPPRESS on readings and adjust voltage source to 1.5V.

2.5.7 IV Example

Setting up an IV measurement is, for the most part, quite similar to setting up a CV measurement. Follow steps 1-20 of CV example in paragraph 2.5.5. Then perform the steps described below. (NOTE: This example is based on the same measurement configuration described in paragraph 2.5.6.)

Button Press	Display		Remarks
MEASURE IV			
1. CURRENT	−0.002	nA	Place unit in CURRENT function (then press RANGE ▲ to put instrument to appropriate range; in this case, the 20μA range).
(CONNECT RESISTOR)			
2. SHIFT, then ▼ LIMIT	−01.00	V	Display and PRESET the voltage source.
3. DISPLAY SOURCE	0.002*	μA	Return display to meter.
4. ZERO CHECK	−1.0158*	μA	Turn off ZERO CHECK.
5. SELECT ▼	XX.XXX	μA	Current readings during staircase; constant DC readings when staircase reaches upper LIMIT.

*This value depends on resistor under test, stray currents, etc.

SECTION 3
OPERATION

3.1 INTRODUCTION

Detailed front panel operation of the Model 595 is described in this section, including test connections and complete front and rear panel descriptions in the first half (Part 1), and how to make CV, IV and Q/t-V plots is described in the second half (Part 2). Many of these operations can also be programmed over the IEEE-488 bus, as described in Section 4.

PART 1
Front and Rear Panel Descriptions

3.2 TEST CONNECTIONS

The following paragraphs will describe how to set up typical capacitance and current measurements with the Model 595. Connections can be made with the supplied Model 4801 cables; in addition, other low noise, coaxial BNC cables may be used with the Model 595. In any connection to this instrument, it is advisable to use the shortest cables practical for the particular test setup. In situations where vibration may be present (such as a vacuum pump), tape the cables to a stable object to avoid excessive vibration and electrical noise. Note: see warnings in paragraph 2.5 before operating instrument.

3.2.1 Capacitance Connections

Many applications of the Model 595 will involve using the instrument to determine capacitance of devices on semiconductor wafers. A variety of probe station setups are available; the precise configuration of such a station is up to the user, depending on his needs and equipment available to him. However, most of these setups will use connections similar to those illustrated in Figure 3-1A with the test fixture completely enclosed in a light-tight metal box for electrical shielding. The metal box should be connected to GUARD. Note that the Model 595 VOLTAGE SOURCE OUTPUT is connected to the substrate (to minimize the effects of stray capacitance and noise); and the INPUT is attached to the probe.

Packaged capacitors should also be measured in a shielded metal box and are connected as illustrated in Figure 3-1B.

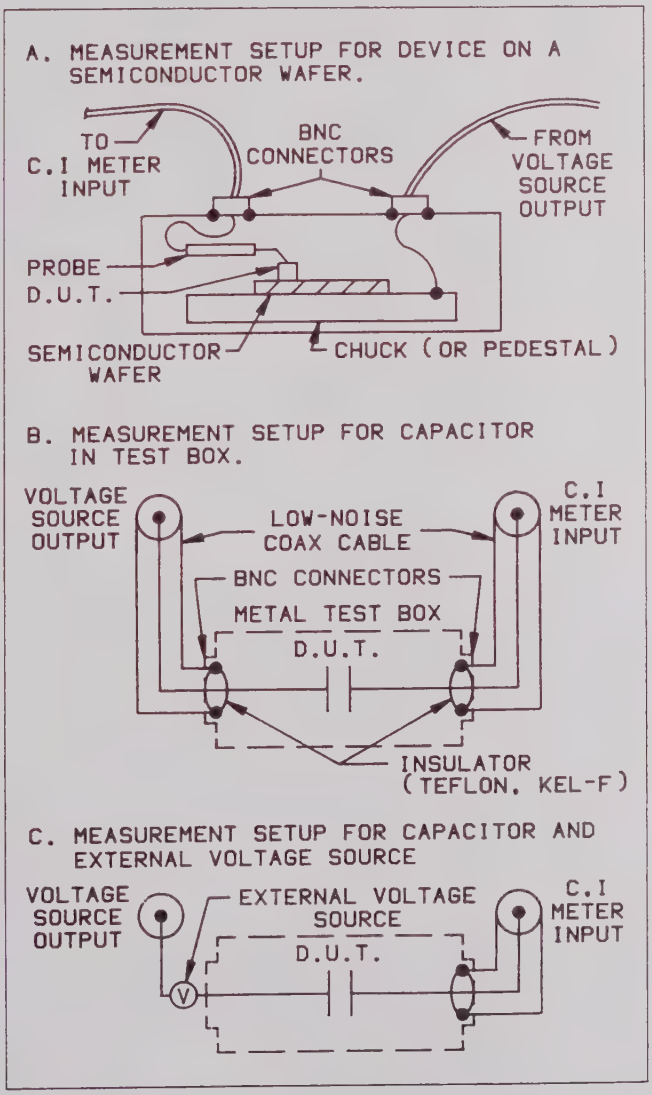


Figure 3-1. Capacitance Measurement Connections

3.2.2. Connections for Current Measurements

The Model 595 is capable of making current measurements in addition to capacitance measurements.

Although current measurements may not require the use of a voltage source, the current function can be used with the voltage source to determine a resistance value (by Ohm's Law, V=IR) or to generate IV curves.

Figure 3-2A illustrates a typical current measurement setup with an external voltage, and Figure 3-2B shows a standard circuit using the instrument's internal voltage source.

Again, low noise coaxial BNC cables and a metal test box to shield the device should be used for best results.

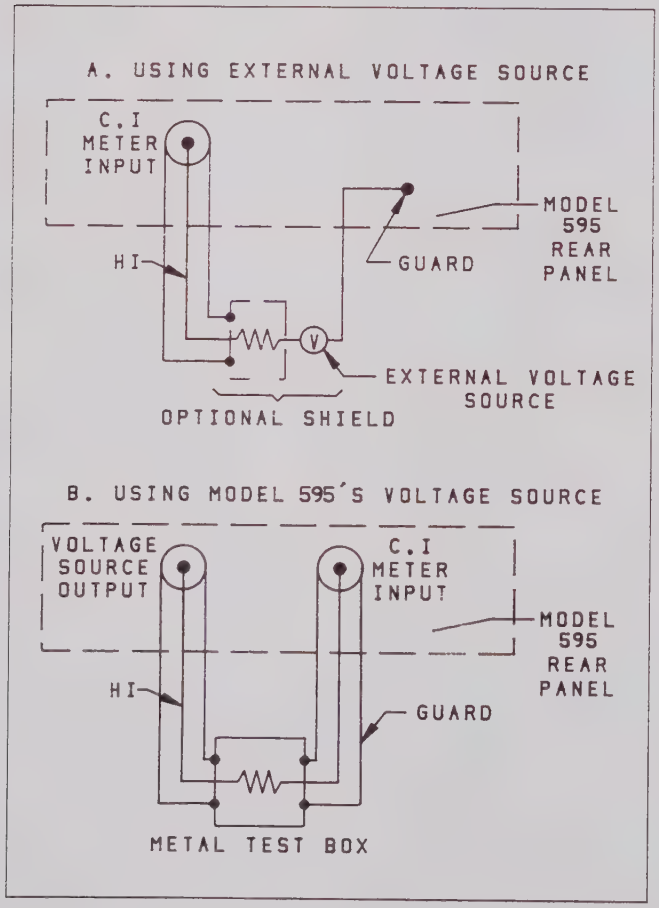


Figure 3-2. Connections for Current Measurements

3.3 DETAILED FRONT PANEL CONTROL DESCRIPTIONS

This section gives complete descriptions of all Model 595 front panel controls. Note that the front panel buttons are arranged and characterized by color-coded "blocks"—METER block, WAVEFORM block, VOLTAGE SOURCE block, and PROGRAM block. The SHIFT button is used to access second functions, which are labelled in yellow.

METER Block

The following controls are found in the METER block of the Model 595 front panel.

3.3.1 CURRENT

The CURRENT button places the Model 595 in the current measurement function. The indicator light next to the button is on when this function is selected. Any one of eight ranges (20pA to 200μA) may be used with this function.

3.3.2 CAPACITANCE

The CAPACITANCE button places the Model 595 in the capacitance measurement function. The red indicator light is on when this function is selected. There are three capacitance ranges: 20nF, 2nF and 200pF.

When making a capacitance measurement, the Model 595 makes three charge measurements around the voltage source "step" (the STEP waveform must be selected). See Figure 3-3. From these three charge measurements the capacitance and the current through the device (at the end of the delay time) are calculated. The voltage reported with the reading is the source voltage (V_1) plus half of the step voltage.

Q/t displays the current flowing through the device at the end of the delay time. This is selected by pressing SHIFT, then the CAPACITANCE Q/t button. Note: the capacitance function must be selected to select Q/t. The yellow indicator light is on when the Q/t current is being displayed.

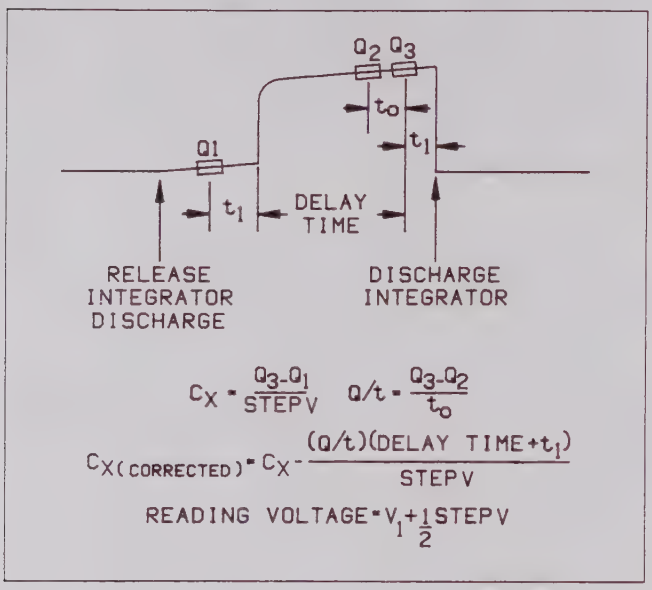


Figure 3-3. Integrator Charge vs Time Curve for a Capacitance Measurement

3.3.3 C/C_o-STORE C_o

C/C_o allows the user to normalize capacitance to a stored capacitance value (C_o). C/C_o applies only to the capacitance reading (even while Q/t is being displayed). To store a capacitance reading (C_o), simply set up the desired capacitance measurement, then press SHIFT, then STORE C_o. The next reading will be stored as C_o. To normalize the capacitance readings to C_o, press C/C_o (the LED will come on). This will divide all subsequent readings by the stored reading, C_o, and show the resulting quotient on the display. Once a value of C_o is stored, it will be retained in memory until a new value is stored or the instrument is turned off.

C/C_o allows comparison of the relative shapes of two or more CV curves even when absolute capacitance values may be different.

3.3.4 SUPPRESS

The SUPPRESS button allows the user to compensate for external offsets present in the test setup by subtracting the offset value from subsequent readings. (To compensate for internal offsets, see ZERO CHECK and CORRect.) Suppress may be used with capacitance or current measurements, but not Q/t.

When the SUPPRESS button is pressed, the instrument will store the next measurement as a baseline. The SUPPRESS indicator light will illuminate. All subsequent readings taken will be the difference between the measured value and the stored baseline.

The baseline maintains its absolute value regardless of range. For example, if a 0.1nF signal is suppressed on the 2nF range, it will remain at 0.1nF on the 20nF and 200pF ranges. Only one reading for the presently selected function can be suppressed; the value will be lost if the function is changed. The instrument can be toggled between Q/t and capacitance without losing the stored value.

The suppressed readings can be as small as the resolution of the instrument will allow, or as large as full range (see Note 1). Some typical examples include:

Applied Signal	Suppressed Reading	Displayed Value
30 pF	0.5 pF	29.5 pF
– 1.5 nA	– 1 nA	– 0.5 nA
11.3 nF	13 nF	– 1.7 nF
0.10pA	– 0.01pA	0.11pA

NOTES:

1. Using suppress reduces the dynamic range of the measurement. For example, if the suppressed value is 100.00pA on the 200pA range, an input current of more than 99.99pA would overrange the instrument even though input currents up to 199.99pA are normally within the capabilities of the 200pA range.
2. Setting the range lower than the suppressed value will overrange the display; the instrument will display the "OL" message under these conditions.
3. To store a new baseline, suppress must first be disabled and then enabled once again. The next reading taken will be stored as the new baseline.
4. Enable suppress on the measurement range that yields the highest resolution for the application.
5. If the instrument is displaying Q/t when suppress is enabled, the capacitance value will be suppressed even though the capacitance reading is not displayed. Suppression has no effect on Q/t readings.

3.3.5 ZERO CHECK and CORRect

Zero check is used to protect the input amplifier of the Model 595 from overloads and switching transients when changing instrument functions or connections to the device

under test. Therefore, make sure the ZERO CHECK indicator light is on when changing functions or connections. The ZERO CHECK button toggles the instrument in and out of zero check.

Zero check is also used with zero correct to cancel internal offsets in the Model 595 input amplifier. Zero correction is not applicable to capacitance or Q/t but should be performed for the current function on the 20pA range.

Note that the specifications at the front of this manual assume that the instrument has been properly zeroed. The following procedure should be used after the instrument has warmed up for two hours and repeated as needed every 24 hours or if the ambient temperature changes by more than 1°C.

1. Select the current function and the 20pA range.
2. Press the ZERO CHECK button and be sure the ZERO CHECK indicator light is on. The Model 595 input amplifier is now configured to read its own internal offset.
3. Press SHIFT, then CORRect to zero correct the instrument. Note that if zero check was not enabled, the zero correct operation will enable zero check first.
4. The proper range may now be selected and ZERO CHECK released to make a measurement.

NOTES:

1. Remember to leave zero check enabled when connecting or disconnecting input signals, or when changing ranges or functions.
2. The zero correct value is stored in permanent memory and is maintained while the instrument is turned off. A new zero correct value always replaces an older one.

3.3.6 RANGE ▲, ▼

The Model 595 has several ranges available for both capacitance and current measurements. The capacitance ranges are 20pF, 2nF and 20nF. The current ranges are 20pA, 200pA, 2nA, 20nA, 200nA, 2μA, 20μA and 200μA. The instrument powers up on the 20nF capacitance range.

When making a measurement, choose the lowest range possible without overloading the Model 595. This will maximize measurement resolution.

The RANGE ▲, ▼ buttons in the METER block of the Model 595 allow the user to increment or decrement the range. The ▲ range button selects the next higher range and the ▼ button selects the next lower range.

WAVEFORM Block

The following controls are found in the WAVEFORM block of the Model 595 front panel. The SELECT ▲, ▼ buttons are used to select the voltage waveform.

The Model 595 is capable of sourcing either DC or a stepped voltage to the device under test. At power up, the Model 595 is set to measure capacitance, and the waveform is set to square wave.

OFF 0.0V

OFF sets the voltage source to 0.00V ±0.01V. This can be used to set the voltage source to zero without having to use the ADJUST buttons. If capacitance is selected, an "OFF" message will appear on the display since a step is necessary to measure capacitance.

DC

When DC is selected, the voltage source will output a constant voltage, equal to the voltage source programmed value. If the capacitance function is selected, the "DC" message will appear on the display since a step is necessary to measure capacitance.

STEP

The STEP waveform is the fundamental signal required for capacitance measurements. Two STEP waveforms are available: square wave and staircase. The characteristics of this waveform are tailored using the controls within the VOLTAGE SOURCE block.

The instrument powers up with square wave selected.This is the waveform used to measure capacitance at a specific test voltage. Refer to Figure 3-4 for a diagram of the waveform. The voltage starts at V1 (set by the user in the range of −20 to +20 volts). After the programmed delay

time (plus 0.04sec) the voltage changes by STEP V. The output voltage remains at this level for another delay time (plus 0.04sec) and then returns to the original V1 level. The output voltage continues to repeat the above process. For capacitance measurements, the reading voltage is reported as $V_1 + \frac{1}{2} V_{STEP}$. For current measurements the reading is reported at the voltage where the measurement was made.

Staircase is selected in the same way as square wave. The timing is also the same but at the end of the second delay time the waveform does not return to V1. Instead, it increments again by STEP V to V2. This results in an output voltage waveform that resembles a staircase—continually increasing (or decreasing) uniformly in steps. When the output voltage reaches the upper or lower limit, the output voltage will switch to DC. To re-start a staircase waveform, set the voltage source output to the desired starting voltage (the "preset" feature makes this easy) and re-select the step waveform.

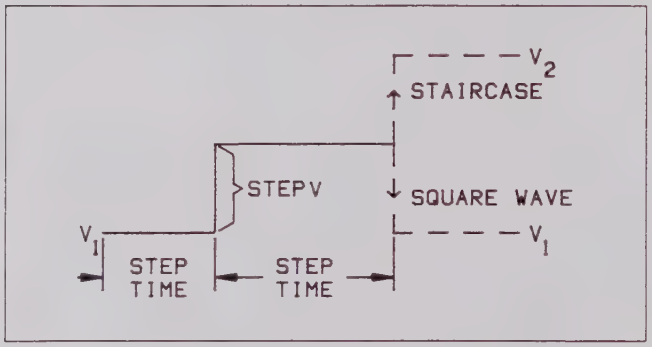


Figure 3-4. Voltage Output Waveform

VOLTAGE SOURCE Block

The Model 595 has a built-in voltage source that is used to make capacitance measurements. It can also be used with the current function for measuring IV characteristics of devices. The output voltage may be set from −20V to +20V in 10mV increments. Limits may be set to prevent the output from exceeding a selected value. The maximum current for which the output voltage is guaranteed is 2mA and current limiting prevents the output current from exceeding 4mA even into a direct short.

The following controls are found in the VOLTAGE SOURCE block of the Model 595 front panel. The indicator lights indicate which parameters are displayed. Press to select a particular parameter, press again to return to the measurement display.

3.3.7 ▲ LIMIT, ▼ LIMIT, and PRESET

The ▲ LIMIT and ▼ LIMIT buttons set the maximum and minimum voltage that the voltage source will output. These limits may be set by the user to protect a device that could be damaged by excess voltage. On power up the ▲ LIMIT is set to +20 volts and the ▼ LIMIT to −20 volts. These power up limits are the maximum and minimum voltages that the limits can be set to.

When a LIMIT button is pressed, the display shows that voltage limit. The ADJUST buttons are used to change that limit in 10mV increments.

An auxiliary function of the voltage limit buttons is PRESET. PRESET allows the user to quickly set the output voltage value to the maximum or minimum limit without having to use the ADJUST buttons. To use PRESET, press SHIFT, then ▲ LIMIT or ▼ LIMIT.

3.3.8 STEP V

When a step waveform is selected, STEP V determines the step size (the small incremental change in voltage) and whether the waveform will be a square wave or a staircase. The step size may be 0.01V, 0.02V, 0.05V, or 0.10V with a positive or negative polarity. On power up, the step voltage is set to +0.05V square wave. Detail description of the voltage waveform may be found under WAVEFORM BLOCK - STEP.

To select the step voltage, press STEP V. The indicator light will be on while the step voltage is displayed. Use the ADJUST buttons to select the step size. The ± button may also be used to change the polarity of the step voltage.

Press SHIFT, then STEP V to toggle the waveform between square wave and staircase. Square wave and staircase are shown pictorially next to the STEP V button.

3.3.9 DELAY TIME

The time from the voltage step to the final charge measurement for a capacitance calculation, or from the step to the measurement in current, is the delay time. Delay time is used to allow the device under test to respond to the change in voltage before measurement. The delay time is not usually critical when performing simple capacitance or IV measurements. It is important when performing capacitance and CV measurements on MOS capacitors.

To change the delay time, press DELAY TIME, then the ADJUST ▲ , ▼ buttons to increment or decrement the time. The delay time can be set from 0.07sec to 199.99sec. On power up, the delay time is set to 0.07sec.

Figure 3-3 shows in more detail where the delay time occurs. The total time of the voltage step is delay time plus T1. T1 is the period necessary for the Model 595 to finish the measurement, and is typically 0.04sec (see specification clarifications at the front of the manual). The total time of the voltage step (delay time plus T1 time) is called the step time.

Another time period important to the capacitance function is T_0 . This is the time period from the middle of charge measurement Q_2 to the middle of charge measurement Q_3. The time period T_0 is 1/8th of the delay time, with a minimum time of 44msec. These two charge measurements are used to calculate the current flowing though the device under test (Q/t). The expression for Q/t is found in Figure 3-3.

3.3.10 DISPLAY SOURCE

The DISPLAY SOURCE button causes the Model 595 to display the programmed output voltage. On power up, the Model 595 is programmed for 0.00 volts.

To view the programmed output voltage, press the DISPLAY SOURCE button. To change the voltage, press the ADJUST ▲ or ADJUST ▼ button to increase or decrease the programmed output voltage.

The +/– button may be used to change the polarity of the voltage (while displayed). The programmed output voltage may be quickly set to the voltage limits by pressing SHIFT, then the ▲ LIMIT or ▼ LIMIT button for the maximum limit or minimum limit, respectively.

The indicator light adjacent to the DISPLAY SOURCE button is on when the programmed output voltage is being displayed. This light will flash when the output voltage current limit becomes active. The voltage source is capable of outputting 2mA, after which the output voltage will begin to change and not match the voltage source setting. The current limit will prevent the output current from exceeding 4mA.

3.3.11 ADJUST ▲ , ▼

The voltage source ADJUST buttons are used to increase or decrease the values of ▲ LIMIT, ▼ LIMIT, STEP V, DELAY TIME and the programmed output voltage. To quickly adjust these voltage source parameters, press SHIFT, then the appropriate ADJUST button. Note that while readings are being displayed, pressing either of the ADJUST buttons will change the programmed output voltage.

NOTE

The ADJUST buttons are also with front panel programs. See paragraph 3.4.

3.3.12 +/–, Front Panel Trigger

The +/– button of the Model 595 allows the user to change the polarity of the voltage source while the programmed output voltage is being displayed. It can also be used to change the polarity of STEP V while STEP V is displayed. A secondary feature of the +/– button is that it can be used as a trigger source from the front panel when another trigger source is not available (press SHIFT, then +/–). See paragraph 3.4.4 for information on triggering.

3.4 FRONT PANEL PROGRAMS

The Model 595 has several capabilities that are accessed as "front panel programs". These programs operate through the MENU button. To scan the available programs, simply press MENU. Each additional press of the MENU button will move the menu to the next program. To exit, press SHIFT, then EXIT. Table 3-1 lists the available front panel programs.

Table 3-1. Front Panel Programs

Display	Message	Description
Fr= *‡	Frequency	Power Line frequency setting. Fr=50Hz, Fr=60Hz
CAL *‡	Calibration	Allows calibration of instrument.
FILt	Filter	Selects filter 0-3, see section 3.4.3
trIG	Trigger	Trigger mode: 0=continuous, 1=one shot
Aout	Analog Output	C, I voltage at rear panel ANALOG OUTPUT binding posts. 1=X1 gain, 10=X10 gain
cCAP	Corrected Capacitance	Corrects capacitance readings for error currents. 1=correction on, 0=correction off. See Section 5.3.4 before using.
IEEE *	IEEE-488 Address	IEEE-488 Address Selection Program.
dISP *	Display	Sets numeric or alpha exponent.
y HI 2 †	Y HIGH	Plotter Y-axis high limit.
y Lo 2 †	Y LOW	Plotter Y-axis low limit.
Grid †	Grid	Sets and plots grid for IEEE-488 data graphing.

* Stored in permanent memory.
† Appears in MENU only when address code 42, 43 is selected.
‡ Appears in MENU only when calibration is enabled.

3.4.1 Power Line Frequency

The line frequency program is used to set the Model 595 to the available line frequency (either 50 or 60Hz). This program is accessed as part of the calibration procedure and is discussed in Section 7. During normal operation this front panel program will not appear in the MENU.

3.4.2 Calibration

An advanced feature of the Model 595 is digital calibration. The instrument can be calibrated from the front panel or over the IEEE-488 bus. To use front panel or IEEE-488 bus calibration, refer to the calibration procedures outlined in Section 7. During normal operation this front panel program will not appear in the MENU.

3.4.3 Filter

The Model 595 has three digital filters that can be used to minimize the effects of noise on individual measurements and plotted curves. To use the filter program, press the MENU button until "FILt" appears on the display. Next to "FILt" is a number. If the number is zero, then the filter is off, and the actual unmodified curve will be plotted. To advance to a higher level filter, press the voltage source ▲ ADJUST button. To decrease a filter level, press the voltage source ▼ ADJUST button. To exit from the program, press SHIFT and then EXIT.

The suitability of each of these for "curve smoothing" should be determined by considering the number of measurements or samples in the curve; specifically, the fundamental portion to be studied (region of interest).

Filter 1 is used when there are 20 or more samples in the fundamental change area of the curve. This filter provides minimal smoothing of the curve. Filter 2 should be used when there are 50 or more samples in the fundamental portion of the curve for maximum curve smoothing. Lastly, filter 3 is available to smooth slowly changing DC signals (or curves with more than 200 samples in the fundamental portion). This filter should normally only be used with DC signals since it would distort most CV or IV curves.

Figure 3-5 shows an example of proper and improper use of a filter on a curve with 60 readings in the region of interest. Notice the distortion of the curve using Filter 3.

An important characteristic of each filter is its "window". Each filter takes the weighted average of a certain number of readings. This average is symmetrical about the middle reading. Filter 0 (when filter is "off") has a one reading window, Filter 1 has a three reading window, Filter 2 has a nine reading window, and Filter 3 has a 24 reading window.

The weightings (or coefficients) assigned to each reading are as follows:

Level 1: 1/4, 1/2, 1/4

Level 2: −1/32, 1/32, 1/8, 15/64, 9/32, 15/64, 1/8, 1/32, −1/32

Level 3: 1/32, 1/32, 1/32, 1/32, 1/32, 1/32, 1/32, 1/32, 1/16, 1/16, 1/16, 1/16, 1/16, 1/16, 1/16, 1/16, 1/32, 1/32, 1/32, 1/32, 1/32, 1/32, 1/32, 1/32.

Figure 3-6 illustrates the coefficients of Filter 2.

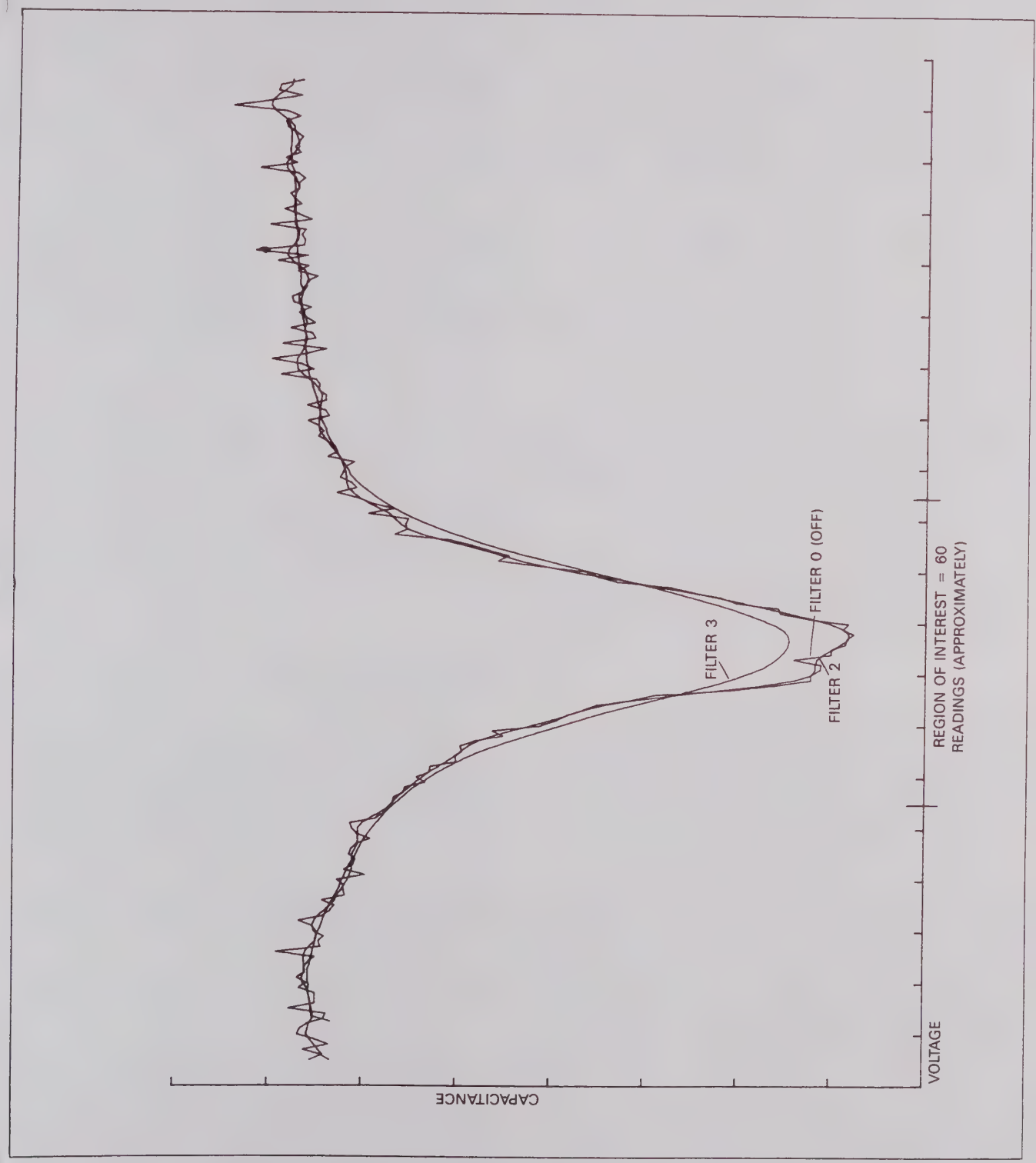


Figure 3-5. Example: Using the Filter on a MOS Device Curve

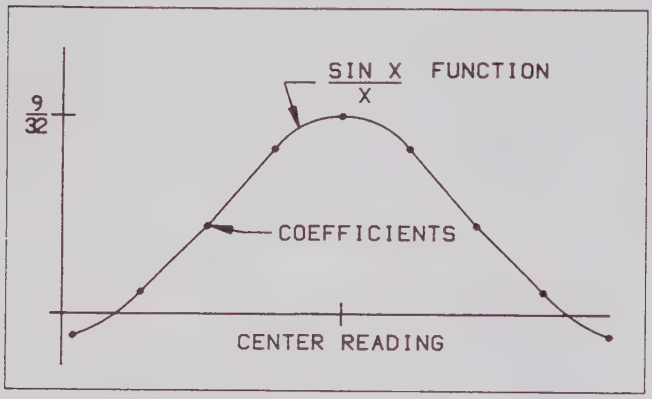


Figure 3-6. Coefficients in Filter 2

The coefficients are chosen to approximate the Fourier components of a brick wall filter [(sin X)/X]. The passband of the filter is chosen to pass the signal curve while attenuating noise outside the passband. Typical white noise reduction is as follows: Level 1, 1.7; Level 2, 2.5; Level 3, 5.0.

Since the filter is symmetrical, there is a delay between what is displayed (middle reading) and the measurement being taken. Filter 0 has a one reading delay, filter 1 has a two-reading delay, filter 2 has a five-reading delay, and filter 3 has a 13-reading delay.

If a meter or voltage source parameter is changed, the filter is "cleared" and starts over. Changes in step size, delay time, filter type, trigger mode, voltage limits, voltage source, function and range will restart the filter. (The only parameters that don't affect filter operation are C/C_0, STORE C_0, Q/t and SUPPRESS). The filter is cleared during OL readings and while zero check is on, for fast reading response.

When the filter is first enabled or starts over, there is an initial reading delay. Each location in the filter is initially filled with the first reading and subsequent readings pass through the filter. This can be seen on plotted curves. Curves plotted with filter 0 will start plotting one reading after it starts staircasing, filter 1 will begin plotting two readings later, filter 2 will begin five readings later, and filter 3 will begin 13 readings later. Similarly, these filters will finish early by the same number of readings, leaving an unplotted region at the end.

3.4.4 Trigger

A "trigger" is a stimulus to the Model 595 to begin a measurement. Triggering may be done in two basic ways: continuous or one-shot. In continuous, the stimulus starts a series of measurements. In one-shot trigger, a single measurement will be processed each time a trigger stimulus is received. On power up, the Model 595 is in continuous trigger and the stimulus is internally generated to start the measurements.

To access the trigger mode from the front panel, press the MENU button until the message "triG" appears on the display. Next to "triG" a 0 or 1 appears. Zero signifies that the instrument is in continuous trigger and 1 signifies one-shot trigger. To change trigger functions, press either one of the voltage source ADJUST buttons to toggle the trigger mode between 0 and 1. After the desired trigger type is displayed, exit from the program by pressing SHIFT, then EXIT.

To send the instrument a trigger from the front panel, press SHIFT, then +/−.

The Model 595 can also respond to other trigger stimuli besides the button sequence from the front panel. The rear panel has an external trigger input connector (see paragraph 3.5.1) and various commands over the IEEE-488 bus can be used as a trigger stimulus (see paragraph 4.9.18).

NOTE: The button sequence, SHIFT, +/−, will always generate a trigger unless the front panel operation is locked out from the IEEE-488 bus.

3.4.5 Analog Output X1/X10

The analog output program allows the user to set the C, I analog output gain to X1 or X10. X1 is used for readings over 10% full range. With a maximum input of ±19999 counts, output is ±2V. (This is equivalent to 1V on output for 10,000 counts on the display). X10 is used for readings less than 10% of full range. With a maximum input of ±2000 counts, output is ±2V. (This is equivalent to 1V output for 1000 counts on the display).

To access the analog output program, press MENU until "Aout" is displayed. A message of "Aout 1" means gain is X1; "Aout 10" means gain is X10. Press either of the voltage source ADJUST buttons to toggle the gain between X1 and X10.

The analog output signal is available on the rear panel ANALOG OUTPUT connector, and follows the C, I or Q/t display.

Note that the selected analog output gain is not saved when the instrument is turned off. When the Model 595 is powered on again, the gain will default to X1.

3.4.6 Corrected Capacitance

This program allows the capacitance reading to be corrected for the effects of leakage currents. It must be determined that the device under test has completely responded to the change in voltage used in the measurement and that the Q/t current is only related to DC errors such as leakage current or low oxide resistance. In these cases, CORRECTED CAPACITANCE uses the Q/t measurement to cancel the effects of these DC error currents on the capacitance reading. The capacitance is then calculated by:

$$Cx\ (\text{corrected}) = Cx - \frac{(Q/t)(\text{delay time} + t_1)}{\text{Step V}}$$

(Refer to Figures 3-3 and 3-4 for diagrams of the variables used.)

NOTE: Using corrected capacitance can cause erroneous results if the device under test is not in equilibrium. See paragraphs 5.3.3 and 5.3.4 for information to determine conditions for equilibrium and proper use of the capacitance correction program.

To use this program, press the MENU button until "cCAP" is displayed. A 0 signifies that correction is off, and 1 means that corrected capacitance has been enabled. To toggle corrected capacitance on or off, simply press either of the voltage source ADJUST buttons. Note that the Model 595 always powers up with corrected capacitance off.

3.4.7 IEEE-488 Address

Selection of the IEEE-488 address function is indicated by the following menu message:

IEEE 28

Along with the message, the presently programmed IEEE-488 address (28 in this example) will be displayed. To change the value, use the voltage source ADJUST ▲ , ▼ buttons. When the desired value is shown on the display, press SHIFT, then EXIT to return to normal operation. Addresses 0 to 30 are the normal IEEE-488 addresses. Codes 40 and 41 allow the Model 595 to control an IEEE-488 printer. Codes 42 and 43 allow the Model 595 to control an IEEE-488 plotter. For complete information on controlling the Model 595 over the IEEE-488 bus, refer to Section 4. For plotter and printer information, see paragraph 3.9 and 3.11.

NOTE

When actively outputting data while set to codes 40-43, the Model 595 acts as a controller, and by IEEE-488 conventions should be the only controller on the bus at that time (although multiple Model 595s, or 590s are permitted provided only one instrument at a time is talking).

3.4.8 Display (Alpha or Numeric)

The front panel exponent of the Model 595 can be set to display in either alpha or numeric characters. When in alpha, the exponent is given in actual units such as nF. When in the numeric display function, the exponent is given in scientific notation. Table 3-2 gives typical examples, including units.

Table 3-2. Display Exponent Values

Display	Engineering Units	Scientific Notation	Value
nF	nF	10^{-9}F	Nanofarads
PF	pF	10^{-12}F	Picofarads
μA	μA	10^{-6}A	Microamperes
nA	nA	10^{-9}A	Nanoamperes
PA	pA	10^{-12}A	Picoamperes
SQ	V		Square wave voltage waveform
ST	V		Staircase voltage waveform
S	s		Seconds

To select the exponent program, scroll through the program menu until the following message is displayed:

dISP

Use either of the voltage source ADJUST buttons to set the exponent to the desired display. In the numeric function, the display will show:

dISP −6

The alpha display appears as:

dISP μ

Once the desired type of exponent is selected, press SHIFT, then EXIT to return to normal operation.

Plotter Parameters

The following front panel programs can only be accessed (from the menu) when the Model 595's IEEE-488 address has been set to code 42 or 43.

NOTE

When the IEEE-488 address is set to 42, the X axis is plotted from ▼ limit to ▲ limit (left to right). When the IEEE-488 address is set to 43, the curve is "flipped" over on the X axis and is plotted from the ▲ limit to the ▼ limit.

3.4.9 Grid

The grid program allows the user to plot a grid on an HPGL compatible plotter (HP7470A or equivalent) with the Model 595 acting as a controller. The plotter should be set to address 5. The grid will be plotted according to the function, range and limits the Model 595 is currently set to at the time the grid is initiated.

After code 42 or 43 has been selected, press the MENU button until the message "Grid" appears on the display ("Grid" is the third program on the menu). (NOTE: if no plotter is actually attached at this time, the front panel controls will be inoperable for five seconds while the Model 595 tries to access the plotter). Finally, press either of the voltage source ADJUST buttons, and the plotter will begin to draw the grid. The front panel buttons are inoperable while the grid is being drawn.

3.4.10 Y HI — Y Lo

The Y HI – Y Lo programs are used to set the upper and lower limits of the Y axis when plotting. The limits run from ±0.1 to ±2.0 in 0.1 increments, with 2.0 corresponding to a full 20,000 count display and 0.1 corresponding to 1000 counts. The user can thus adjust Y HI and Y Lo to "crop" the plot as desired.

After code 42 or 43 has been selected, press the MENU button until "Y HI 2" appears (or press MENU once more to display "Y Lo –2"). To change the program values, press the voltage source ADJUST buttons. Once the desired limit is displayed, press SHIFT, then EXIT to leave the menu.

NOTES:

1. The Y axis limit values are not stored in permanent memory and will return to their defaults if power is cycled to the Model 595.
2. A change of function, range or voltage limits will affect the correlation of data to the axis labels.

3.5 REAR PANEL FEATURES

3.5.1 External Trigger

The Model 595 on power up is set to recognize the rear panel EXTERNAL TRIGGER INPUT. Continuous trigger or one-shot trigger may be selected by the front panel program (see paragraph 3.4.4), or over the IEEE-488 bus. The commands for external trigger are T6 (continuous) and T7 (one-shot).

The EXTERNAL TRIGGER INPUT requires the falling edge of a TTL logic level pulse as shown in Figure 3-7. The low logic level should be between 0 and 0.8V, and the high level should be 2.0 to 5.0V. The minimum pulse width for reliable triggering is 10μsec. Connections to the rear panel EXTERNAL TRIGGER INPUT jack should be made with a standard BNC connector.

To use external triggering, proceed as follows:

1. Connect the external trigger source to the rear panel BNC EXTERNAL TRIGGER INPUT connector. The shield (outer) part of the connector is connected to IEEE common. There is an internal pull-up resistor so a mechanical switch may be used. Note, however, that debouncing circuitry will probably be required to avoid improper triggering.

CAUTION

Do not exceed 30V between IEEE common and chassis ground, or a shock hazard may be present.

2. Place the instrument in one-shot trigger by pressing MENU to get into triG, then use either voltage source ADJUST button to set the display to "triG 1".
3. To trigger the instrument, apply a pulse to the EXTERNAL TRIGGER INPUT. The instrument will process a single reading each time the pulse is applied. Alternatively, the instrument may be triggered from the front panel by pressing SHIFT, then the +/– button.
4. To get out of one-shot, set triG program display back to 0, then press SHIFT, then EXIT. A trigger stimulus will be required to resume continuous measurements.

NOTES:

1. The Model 595 must be set to the appropriate trigger mode, T6 or T7, to respond to external triggering. Note that the instrument is set to T6, Continuous on External Trigger, on power up.
2. If a trigger overrun occurs (the instrument is triggered while processing a reading from a previous trigger), it will ignore the trigger and display: "tErr".

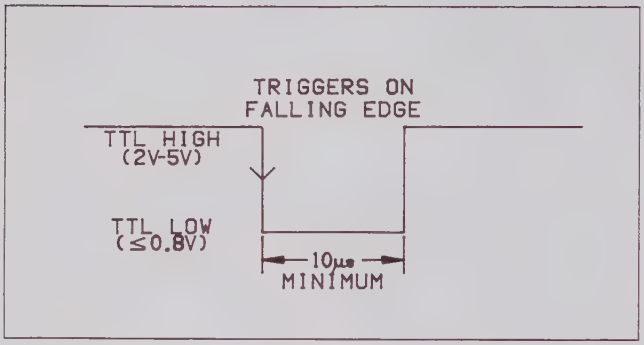


Figure 3-7. External Trigger Pulse Specifications

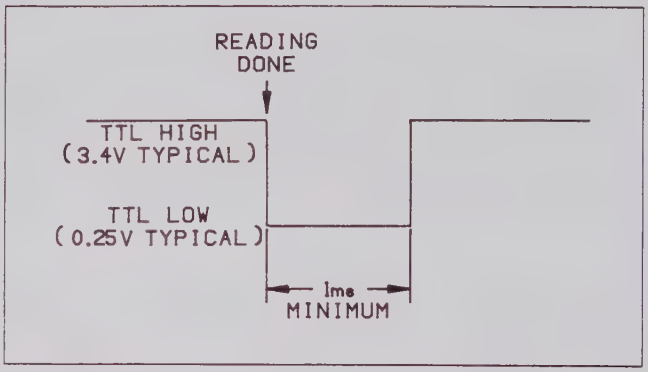


Figure 3-8. Meter Complete Pulse Specifications

3.5.2 Meter Complete

The Model 595 can be programmed to output a pulse that can be used to trigger other instrumentation. A single TTL-compatible negative-going pulse with a minimum duration of 1msec (see Figure 3-8) will appear at the METER COMPLETE OUTPUT jack each time the instrument completes a reading. To use the meter complete output, proceed as follows:

1. Connect the Model 595 to the instrument to be triggered with a suitable shielded cable. Use a standard BNC connector to make the connection to the Model 595.

CAUTION
Do not exceed 30V between the METER COMPLETE common (outer ring) and chassis ground or a shock hazard may be present.

2. Select the desired function, range, trigger, and other operating parameters as desired.
3. In continuous trigger, the instrument will output pulses at the reading rate; each pulse will occur after the Model 595 has completed a reading.
4. In one-shot trigger, the Model 595 will output a pulse once each time it completes the reading conversion.

3.5.3 Analog Outputs

The rear panel outputs available to plot data from the Model 595 are: C, I ANALOG OUTPUT and V ANALOG OUTPUT. These outputs work with either an analog X-Y recorder or a chart recorder. (Alternate data outputs include sending data over the IEEE-488 bus to a listening device such as a listen-only or addressable printer, or the instrument could output voltage and capacitance data to an IEEE-488 plotter, such as an HP-7470A or equivalent, to plot CV, Q/t V, or IV curves. See paragraphs 4.11 and 4.12 for more information).

The analog outputs are reconstructed from the IV, CV, or Q/t-V data (using digital to analog converters). The I, C, or Q/t data corresponds to the displayed reading. The V data corresponds to the voltage at which the reading was taken, not the voltage being sourced.

On the C,I output, 1V is equivalent to 10,000 display counts on X1 gain and 1000 counts on X10 gain. On the V output level, 1V = 10V on the voltage source output. The maximum output voltage is ±2V and output resistance is 1kΩ. Response time (reading updates) mirrors the display within 5msec. Isolation is 30V peak from chassis or GUARD to ANALOG OUTPUT LO, which is connected to IEEE common.

The PEN LIFT binding post on the rear panel provides plotter pen lift control. PEN LIFT puts the pen down at the start of a staircase plot and picks it up at the end. (PEN LIFT is only active during staircase measurements.

CAUTION
Do not exceed 30V between the ANALOG OUTPUT COMMON (IEEE COMMON) and chassis ground or a shock hazard may be present.

PART 2
Making CV, IV or Q/t-V Plots

Part 2 of Section 3 will show how to use the features and functions described in Part 1 of Section 3 to take data or plot curves with analog or digital plotters. Part 2 will also discuss listing data points with a printer, the effect of using a filter on curves, and measurement considerations. The procedures that follow are applicable for CV, IV or Q/t-V plots.

3.6 SETTING UP THE TEST FIXTURE

If the voltage source is on, select the OFF waveform to prevent any excessive voltages during the set up. Enable ZERO CHECK to protect the meter's input amplifier, then make all input connections (but leave the device under test disconnected at the device for now).

Now set the voltage source limits below the device damage levels. For example, if a MOS device with a breakdown voltage of 8V is to be measured, set the maximum voltage limit at 6 or 7V to prevent possible damage to the device. Be sure to set both maximum and minimum limits for proper protection.

If current is to be measured, perform zero correction if necessary at this time (see paragraph 3.3.5). This will correct for any internal offsets that may be present in the Model 595.

To cancel any external offsets present in the test fixture for either capacitance or current measurement, suppress the offsets by removing ZERO CHECK (with the device still disconnected as close to the device being measured as possible to cancel offsets) and enabling SUPPRESS.

3.7 SETTING UP MEASUREMENT PARAMETERS

At this point, connect the device under test to the Model 595. In order to determine the appropriate set up to make the plot, it is a good idea to "spot check" the device under test at various voltages.

As an example, consider setting up an IV measurement for a 6.3V zener diode. First, set the waveform to DC. Next, using the voltage source block, apply different voltages to the device to determine its "active" range. For a zener diode, the current will rapidly increase at its reverse zener voltage. Try to find the voltage just before the current rapidly increases and the voltage where the current reaches a plateau. (Note: the Model 595 voltage source current limit will prevent more than 4mA from flowing through the device.) For this example, the region of interest (or area on the curve where the most activity occurs) falls between −6.5V and −4.0V. These voltage levels become the lower and upper limits that should be set for the plot.

Now that the voltage limits are chosen, assume an example with 100 samples (measurements) are desired in the curve. The voltage step size now needs to be determined for the plot. Simply divide the voltage span (difference between the voltage limits) by the number of samples to get the approximate step size. Using the example above gives the following:

$$\frac{2.5\text{V}}{100\text{ samples}} = .025\text{V/sample}$$

NOTE

For capacitance measurements, there are two steps per sample.

In this case, the .02V (20mV) step should be used. If capacitance was being measured, the .01V (10mV) step should be used. Generally speaking, if the step voltage does not exactly match the allowable STEP V setting of the Model 595, then the next closest value should be used (in this case, .02V). Remember--a smaller voltage step (STEP V) will increase the resolution of the curve over the voltage range.

The number of samples in the measurement can also be determined if the voltage span and the step size are known. Divide the voltage span by the voltage step as illustrated by the following example:

$$\frac{2.5\text{V}}{.02\text{V/sample}} = 125\text{ samples}$$

The direction of the measurement should also be determined at this time. For a positive-going staircase, make the STEP V positive, and for a negative-going staircase, make STEP V negative.

The appropriate capacitance or current measurement range must also be set to achieve maximum resolution. Usually

this would be the lowest range that doesn't "overrange" the instrument. For example, to measure a capacitor with an approximate value of 1.5nF, the 2nF range would give a higher degree of resolution than the 20nF range (as long as the change in capacitance vs. voltage does not cause the value to exceed 2nF and overrange the instrument during the test).

Now that the voltage limits, step size and measurement range have been determined, it is time to begin the set of measurements that will form the curve.

3.8 BEGINNING THE MEASUREMENT

Select the DC waveform to keep the instrument from beginning the staircase measurement until the appropriate parameters have been selected. Now, enter the upper and lower voltage source limits as determined from the spot check previously performed (in this example, −6.5V is the lower limit and −4.0V is the upper limit). Also, select the step size, direction, measurement range and delay time.

NOTE

When setting up measurements such as the IV for a zener diode illustrated in this example, delay time is not a critical parameter due to the nature of the device. However, applications involving MOS devices may require that the measurement be sufficiently slow so that the device achieves equilibrium, in which case delay time becomes critical. This delay time, which occurs in the inversion region, is also measurement-direction dependent. If a measurement is changed to DC, the output voltage is moved to the next level where the effective step is off in order to preserve the direction of the measurement. See Applications, paragraph 5.3.3, for information on how to select the appropriate delay time for MOS devices.

Connect the device and turn off ZERO CHECK. To begin the measurement, set STEP V to the staircase waveform, and set the voltage source to the starting voltage level with either the voltage source ADJUST buttons or PRESET. Finally, select the step waveform and the measurement staircase will begin.

To pause the staircase, change the waveform to DC. If desired, the step direction or voltage source can be adjusted at this time, then the staircase can be resumed by returning the waveform to STEP.

Reading rate is a function of delay time. For capacitance measurements, there are two step times for every reading. For current measurements, a reading is ready every step time (delay time +0.04sec).

3.9 DIGITAL PLOTTING

The previous paragraphs described how to initiate a staircase CV, IV or Q/t-V measurement with the Model 595. This section will illustrate how to plot a curve with a digital plotter over the IEEE-488 bus with the Model 595 acting as a controller.

The following HPGL-compatible (Hewlett Packard Graphics Language) plotters are some of the types that may be used with the Model 595 to plot curves: 7470A, 7475A, 7550A, 7580A, 7585A, 7585B, 7586B. The Model 595 uses these HPGL commands to communicate with the digital plotter: IN, IP, SC, PU, PD, PA, IW, LB, SP, and SI. All numeric values are integers except those used with SI.

Use the following procedure to set up the Model 595 and the plotter:

1. Set the waveform to DC and select measurement parameters as determined by the previous paragraphs.
2. Connect the plotter to the bus connector of the Model 595 and set the plotter's IEEE-488 address to 5. Then power up the plotter (NOTE: some plotters only read the address switch on power up). Make sure that Pen #1 is in the holder.
3. Now set the Model 595's IEEE-488 code to 42 or 43 from the front panel IEEE address program. This enables the Model 595 to control the plotter. Select code 42 for a standard plot (voltage on the X axis running from the LO limit (left) to the HI limit) or select code 43 to "flip" the X axis (so that voltage runs from the HI limit to the LO limit). Since the voltage source output is usually applied to the substrate of a MOS capacitor, the gate voltage is effectively the negative of the voltage source output. Code 43 allows the shape of the plot to resemble the usual Capacitance vs. Gate Voltage Curve. (See Appendix for a description of data and control strings sent to the plotter).
4. Choose Y HI and Y LO values if desired from the front panel programs as described in paragraph 3.4.10 to maximize plot resolution on the Y axis.

Having confirmed that all desired measurement parameters have been selected, it is time to plot the grid. After the Model 595's IEEE-488 code is set to 42 or 43, the front panel "Grid" program can be accessed. This program enables the plotter to draw a grid with the X axis labels corresponding to the programmed high and low voltage limits and the Y axis labels corresponding to the Y HI and Y LO capacitance, current or Q/t levels. To plot the grid, press the front panel MENU button until "Grid" appears on the display. Then press one of the voltage source ADJUST buttons and the plotter will begin the grid.

After the grid has been drawn, press SHIFT, then EXIT. To begin plotting the CV, IV or Q/t-V curve, select the STEP waveform. The instrument will initiate a staircase measurement.

EXAMPLE:

Again, consider the example of the 6.3V zener diode IV measurement.

The voltage limits were determined by spot checking to be −6.5V to −4.0V. The voltage step is .02V to give approximately 100 samples over the course of the curve. The delay time is not critical and is left at the factory default of 0.07sec. The Model 595 is set to IEEE-488 code 42 for a standard plot.

After all appropriate parameters are entered, the grid is plotted and the IV curve is run. Analysis of the curve shows that the knee of the curve (or region of interest) actually falls in the region between −6.5V and −5.5V. To increase resolution of the region of interest, the grid and curve are run again with the upper limit now set at −5.5V instead of −4.0V and the step V set at .01V. The resulting curve, illustrated in Figure 3-9, is smoother and gives more information about the region of interest since there are more samples taken in the area.

NOTES:

1. When beginning a data plot, the Model 595 will assume that the displayed quantity (C, Q/t, or I) is the function to be plotted. Once a plot has started in C or Q/t the user can change the front panel display from C to Q/t or vice versa but the plotter will continue plotting the original quantity.
2. If suppress or C/C_0 is altered once the plot has started, the plot will be affected.
3. When the Model 595 is sending data to a plotter there should be no other controller besides the Model 595 on the bus (although multiple Model 595s or 590s are permitted provided only one instrument is talking at a time).
4. When the Model 595 is sending data to a printer or digital plotter, two such listening devices may be connected to the bus providing they are in an addressable mode and are set to the correct address (printer, 3; plotter, 5).
5. When the Model 595 is set to IEEE-488 code 40-43, the device-dependent commands K, G and Y will be affected. See Appendix H for more information.

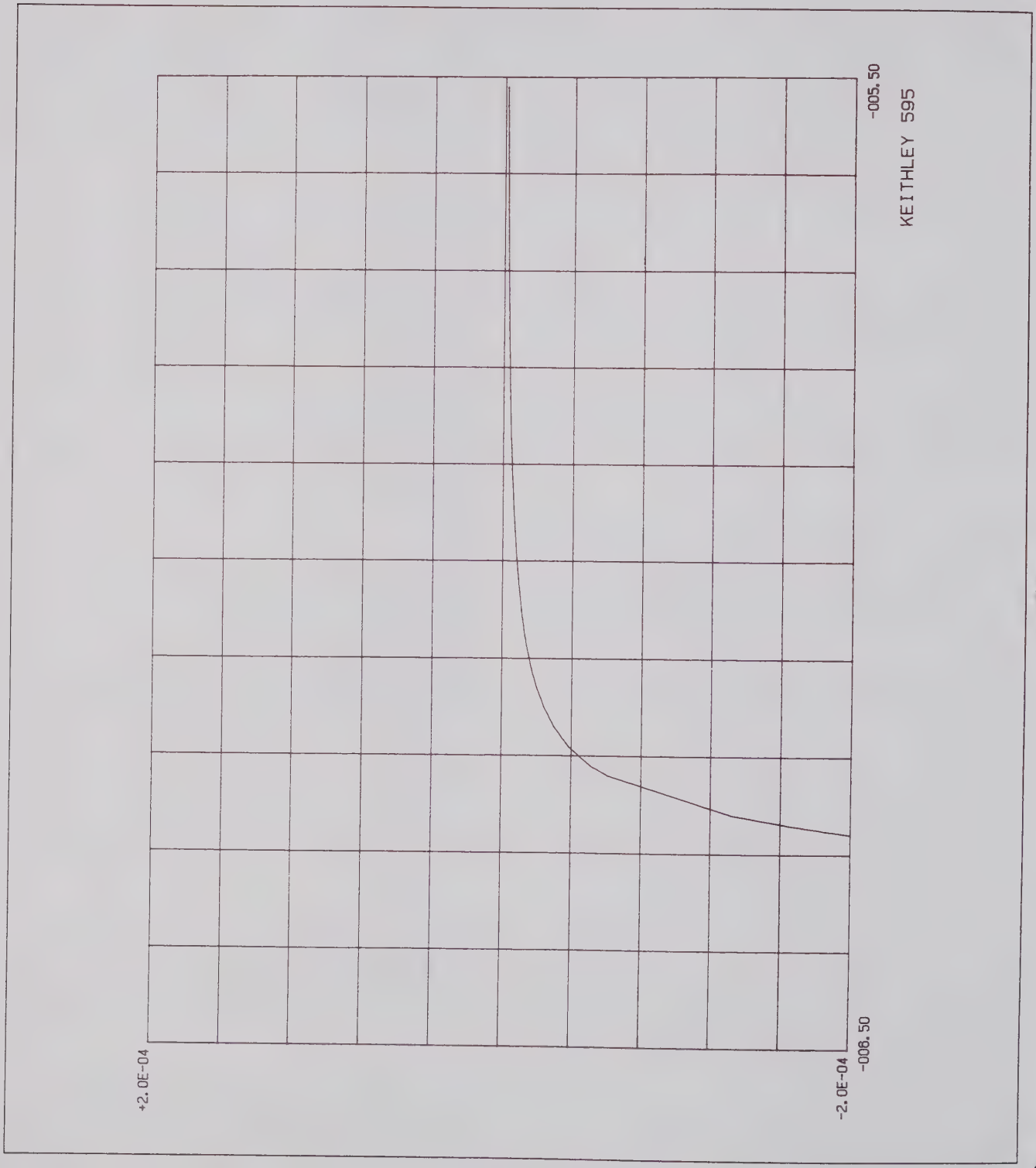


Figure 3-9. IV Curves of a 6.3 Zener Diode

3.10 ANALOG PLOTTING

In addition to sending data over the IEEE-488 bus to plot curves with a digital plotter, the Model 595 can also output data via two rear panel analog outputs to an analog plotter, such as an X-Y recorder.

The staircase measurement described in paragraphs 3.6 through 3.8 is also applicable for measurements to be plotted with an analog plotter. However, the user must draw his own grid and labels. Keep in mind that the maximum output voltage through the rear panel analog outputs is ±2V, so scale the boundaries of the analog plotter accordingly.

The rear panel analog outputs present the displayed reading (C, I or Q/t) and the voltage at which the reading was taken. The user can select X10 gain, if desired, from the front panel analog output program to magnify the C,I output for greater resolution (see paragraph 3.5.3 for more information).

To plot a curve with an analog plotter, set up a staircase measurement with the waveform set to DC as explained in paragraph 3.8. Make sure ZERO CHECK is enabled. Then, make connections between the plotter and the Model 595. Next, set the programmed voltage sensitivity (X axis) and the C, I, or Q/t sensitivity (Y axis) on the plotter. Finally, set the waveform to STEP and the analog plotter will begin to plot the CV, IV or Q/t-V curve.

NOTES:

1. Unlike the digital plotter, the analog output follows the displayed measurement (i.e., C and Q/t).
2. If suppress or C/C_0 is altered once the plot has started, the plot will also be affected.

3.11 PRINTING RESULTS

The Model 595 can output data to a listen-only or addressable IEEE-488 printer. The printer's address must be set to 3.

In order to send data to a printer, the Model 595's IEEE-488 code must be set to either 40 or 41. Code 40 will output data with a prefix on the data string (i.e., NCVI +1.23456E−12, −01.820 + 1.23400E−12). Code 41 will output data without a prefix on the data string (i.e., +1.23456E−12, −01.820 + 1.23400E−12). Note that data sent to the printer from the Model 595 follows the C, I, or Q/t display.

To output data from the Model 595 to a printer, perform the following:

1. Make connections to the device under test and set up measurement parameters.
2. Select the front panel IEEE-488 address program and set the Model 595's address to either 40 or 41.
3. Exit the front panel IEEE program. The Model 595 will output each reading to the printer.

To stop the sequence, change the instrument's IEEE-488 address or select one-shot trigger using the trigger program.

NOTES:

1. When the Model 595 is sending data to a printer there should be no other controller besides the Model 595 on the bus (although multiple Model 595s or 590s are permitted provided only one instrument is talking at a time).
2. When the Model 595 is sending data to a printer or digital plotter, two such listening devices may be connected to the bus providing they are in an addressable mode and are set to the correct address (printer, 3; plotter, 5).
3. When the Model 595 is set at code 40-43, the device-dependent commands K, G and Y will be affected. See Appendix H for more information.
4. At fast reading rates, the printer may not be able to keep up, so some readings will not be printed.

3.12 USE OF FILTER ON CURVES

The Model 595 has three filters to smooth out noisy curves. Filter 1 should be used for curves with more than 20 samples in the region of interest, Filter 2 for curves with more than 50 samples in the region of interest, and Filter 3 for slowly changing DC signals or curves with more than 200 samples in the region of interest.

Figure 3-10 shows three CV curves for a MOS device. There are approximately 60 readings in the region of interest.

Figure 3-10 is deliberately noisy to show the proper use of filters. When Filter 2 is applied, the basic shape of the curve is maintained while the peaks (due to noise) are smoothed out. This is an appropriate application for Filter 2 (Filter 1 was not used since there are more than 50 readings in the region of interest and therefore would not have smoothed the curve sufficiently).

When Filter 3 is used for this application notice that the resulting curve is over-compensated for the effects of noise. Virtually all characteristic peaks have been eliminated, and the lowest point is substantially higher than the lowest point for Filter 2. This figure illustrates the importance of choosing the right Filter to remove noise while maintaining the information in the curve.

See paragraph 3.4.3 for more information on the operation of the Filter.

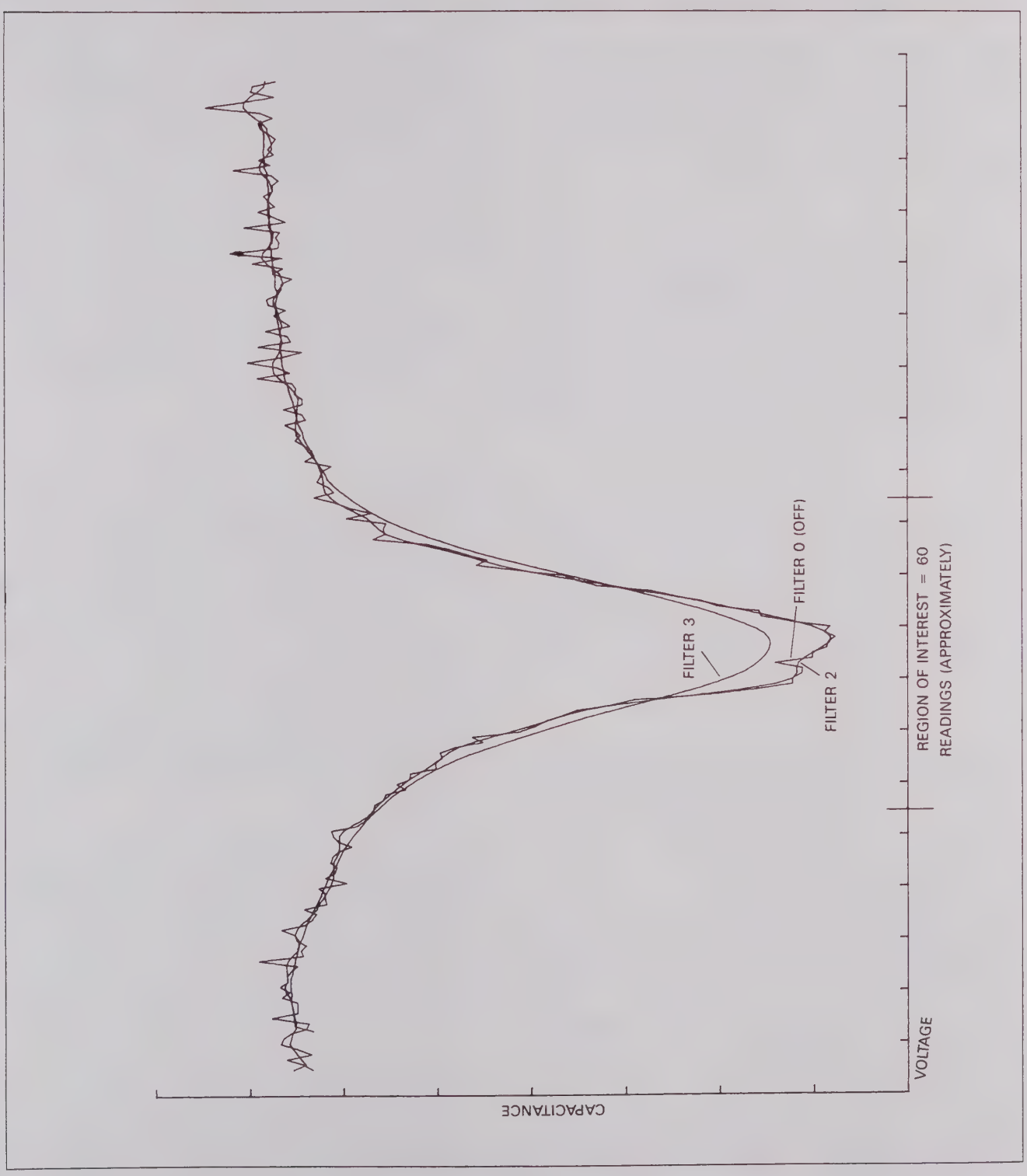


Figure 3-10. MOS Device CV Curve with Filters

3.13 MEASUREMENT CONSIDERATIONS

The Model 595 is a highly sensitive instrument that can measure extremely low signal levels. At these low signal levels, a number of factors can affect a measurement. These factors are discussed in the following paragraphs.

3.13.1 Ground Loops

Ground loops that occur in multiple-instrument test setups can create error signals that cause erratic or erroneous measurements. The configuration shown in Figure 3-11 introduces errors in two ways. Large ground currents flowing in one of the wires will encounter small resistances, either in the wires, or at the connecting points. These resistances result in voltage drops that can affect the measurement. Even if the ground currents are small, magnetic flux cutting across the large loops formed by the ground leads can induce sufficient voltages to disturb sensitive measurements.

To prevent ground loops, instruments should be connected to ground at only a single point, as shown in Figure 3-12. Note that only a single instrument is connected directly to power line ground. Experimentation is sometimes the best way to determine an acceptable arrangement. For this purpose, measuring instruments should be placed on their lowest ranges. The configuration that results in the lowest noise signal is the one that should be used.

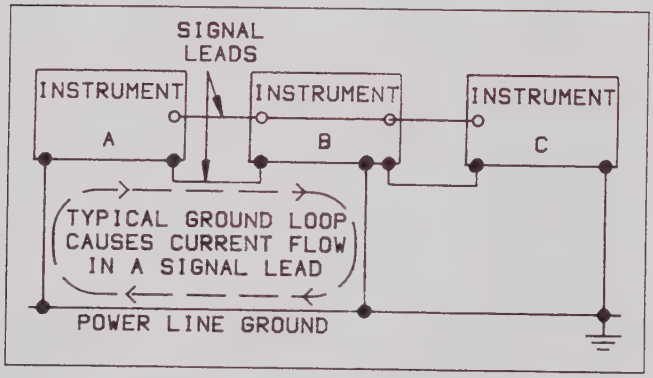


Figure 3-11. Multiple Ground Points Creating a Ground Loop

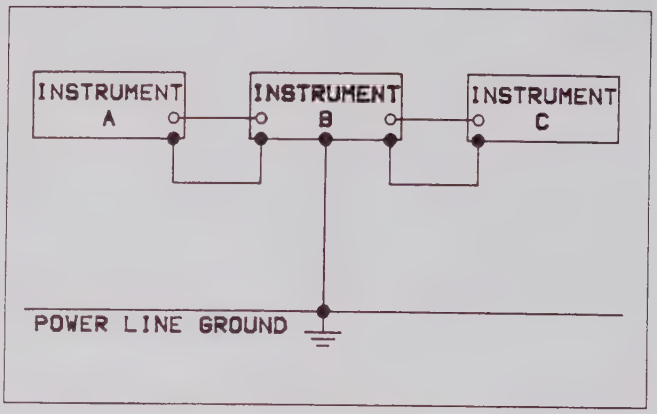


Figure 3-12. Eliminating Ground Loops

3.13.2 Electrostatic Interference

Electrostatic interference occurs when an electrically charged object is brought near an uncharged object, thus inducing a charge on the previously uncharged object. Usually, effects of such electrostatic action are not noticeable because low impedance levels allow the induced charge to dissipate quickly. However, the high impedance levels characteristics of many quasistatic CV measurements do not allow these charges to decay rapidly, and erroneous or unstable readings may result. These erroneous or unstable readings may be caused in the following ways:

1. DC electrostatic fields can cause undetected errors or noise in the reading
2. AC electrostatic fields can cause errors by driving the input amplifier into saturation, or through rectification can produce DC errors.

Electrostatic interference is first recognizable when hand or body movements near the experiment cause fluctuations in the reading.

Methods of minimizing electrostatic interference include:

1. Shielding. Possibilities include: a shielded room, a shielded booth, shielding the sensitive circuit, and using shielded cables. The shield should always be connected to a solid connector that is connected to signal low (GUARD). If signal low is floated above ground, observe safety precautions when touching the shield. Meshed screen or loosely braided cable could be inadequate for high impedances, or in strong fields. The Keithley Model 6104 Test Shield can provide shielding under many circumstances. Note, however, that shielding can increase capacitance in the measuring circuit. The effects of capacitance are discussed in paragraph 3.13.5.
2. Reduction of electrostatic fields. Moving power line or other sources away from the experiment reduces the amount of electrostatic interference seen in the measurement.

3.13.3 Thermal EMFs

Thermal EMFs are small electrical potentials generated by differences in temperature at the junction of two dissimilar metals. Low thermal connections should be used whenever thermal EMFs are known to be a problem. Crimped copper connections can be used to minimize these effects.

3.13.4 RFI

Radio Frequency Interference (RFI) is a general term frequently used to describe electromagnetic interference over a wide range of frequencies across the spectrum. RFI can be especially troublesome at low signal levels, but it may also affect higher level measurements in extreme cases.

RFI can be caused by steady-state sources such as TV or radio broadcast signals, or it can result from impulse sources as in the case of arcing in high voltage environments. In either case, the effect on instrument performance can be considerable, if enough of the unwanted signal is present. The effects of RFI can often be seen as an unusally large offset, or in the case of impulse sources, sudden erratic variations in the displayed reading. In extreme situations it may cause resetting or latch-up of microprocessor-based systems.

RFI can be minimized by taking one or more of several precautions when operating the Model 595 in such environments. The most obvious method is to keep the instrument and experiment as far away from the RFI source as possible. Shielding the instrument, experiment, and test leads will often reduce RFI to an acceptable level. In extreme cases, a specially constructed screen room may be necessary to sufficiently attenuate the troublesome signal.

3.13.5 Source Capacitance

The Model 595 specifications assume that the instrument is used with the supplied Model 4801 Low Noise BNC cables. In practice, it is advisable in both capacitance and current measurements to keep cable lengths as short as possible without applying undue stress to cables or connectors. It is also suggested that fixtures be designed to minimize the stray capacitance between the Model 595 INPUT HI and GUARD terminals.

Occasionally, an application will require that longer cables or test fixtures with significant capacitance from INPUT HI to GUARD be used. The device under test may also have a large capacitance associated with it which is connected from INPUT HI to either GUARD or the VOLTAGE SOURCE OUTPUT. This capacitance is referred to as source capacitance. Source capacitance degrades the instrument performance from the level specified using the supplied cables.

In the current function, the Model 595 is designed to accomodate up to 20,000pF of source capacitance without oscillating or becoming unstable. Increasing source capacitance beyond this level may cause instrument instability. Even within the limit of 20,000pF, source capacitance increases measurement noise. The amount of noise on the current measurement depends on the value of the source impedance (resistance and capacitance combined), the impedance in the feedback loop of the Model 595, and the magnitude of the voltage noise source.

The feedback impedance of the Model 595 in the current function is a resistance (R_F) in parallel with a capacitance (C_F). This combination results in a feedback impedance at the frequency, f, of:

$$Z1 = R_F / \sqrt{(2 \times \pi \times f \times R_F \times C_F) + 1}$$

A generalized source impedance can be considered a parallel resistance and capacitance (R_P and C_P) in series with a resistance (R_S). The impedance of this combination at the frequency f will be:

$$Z2 = R_S + R_P / \sqrt{(2 \times \pi \times f \times R_P \times C_P) + 1}$$

The Model 595 can be thought of as having a noise source in series with its input of $E_N = 10\mu V$ peak to peak in a 0.1 to 10Hz bandwidth. In addition to this voltage noise source, the noise of any other source in the circuit, including the Model 595 voltage source must be appropriately added to E_N. The total noise of all sources is referred to as E_T.

The noise (I_N) on the measured current can then be calculated as follows:

$$I_N = (E_T / R_F) \times (1 + Z1 / Z2)$$

Values of the source impedance (Z2) must be calculated for the specific measurement circuit. External noise sources must be taken into account when determining E_T. Values of R_F and Z1 are determined by the range of the Model 595 and are presented below at the approximate noise bandwidth (f_N). Use f_N for f in the calculation of Z2, since it has been used for the value of Z1 shown.

Ranges	R_F	C_F	Z1 (@f_N)	f_N
pA	10GΩ	57pF	280MΩ	0.28Hz
2nA, 20nA	100MΩ	100pF	84MΩ	10Hz
200nA, 2μA	1MΩ	1010pF	1MΩ	10Hz
20μA, 200μA	10 kΩ	10pF	10 kΩ	10Hz

Note that when Z2 is small, as in the case of a high source capacitance with low series resistance, the quantity Z1/Z2 is large so that the current noise (I_N) is high. In such a situation, the user may add his own series resistance (R_S) to increase Z2, thereby lowering the noise. A side effect of adding R_S is that the response time of the source impedance will increase, because it is proportional to ($R_S \times C_P$). Depending on the noise level desired and the measurement time constraints, an acceptable value of R_S can be chosen.

If source capacitances over 20,000pF cannot be avoided, series resistance (R_S) can be added to prevent oscillation. Values below 10kΩ are not suggested, and a good rule is to choose a value of R_S close to Z1. Keep in mind that the device response time increases proportionally to ($R_S \times C_P$). The resistor type is not critical in terms of tolerance or temperature coefficient. Carbon composition or similar resistor construction should prove adequate.

In the capacitance function, source capacitance will degrade noise performance as it does for the current function. In this case, however, the Model 595 performance specifications take into account the noise due to the value of the capacitance under test and the supplied input cables. Thus only the shunt capacitance between INPUT HI and GUARD in addition to the supplied cables needs to be considered to determine measurement noise.

If the capacitance from INPUT HI to GUARD in addition to the supplied Model 4801 cables is C_S, then the capacitance noise (C_N) for the measurement is:

$$C_N = (1 + C_S / (C_F + 150pF)) \times C_N \text{ (specified)}$$

with the Model 4801 cables

The value of C_S depends on the measurement circuit, but the values of C_F presented below represent the capacitance range selected.

Range	C_F
20nF	1nF
2nF	100pF
200pF	10pF

The capacitance of the Model 4801 cables is approximately 130pF. If these cables are not used, then 130pF should be subtracted from the value of C_S when calculating capacitance noise.

Values of C_S above 20,000pF are not recommended in the capacitance function because they may compromise stability of the measurement. If high shunt capacitance is unavoidable, its effect can be reduced by adding resistance (R_S) in series with a C_S value of approximately 1MΩ. The tolerance and composition of this resistor are not critical.

3.13.6 Engineering Units Conversion

The user may find it helpful in interpreting operation, specifications, and discussion of the Model 595 to understand engineering unit notation. Table 3-3 lists engineering units and their equivalent scientific notation values.

Table 3-3. Engineering Units Conversion

Symbol	Prefix	Exponent
f	femto-	10^{-15}
p	pico-	10^{-12}
n	nano-	10^{-9}
μ	micro-	10^{-6}
m	milli-	10^{-3}
k	kilo-	10^{3}
M	mega-	10^{6}
G	giga-	10^{9}
T	tera-	10^{12}
P	peta-	10^{15}

SECTION 4
IEEE-488 PROGRAMMING

4.1 INTRODUCTION

The IEEE-488 bus is an instrumentation data bus with hardware and programming standards originally adopted by the IEEE (Institute of Electrical and Electronic Engineers) in 1975 and given the IEEE-488 designation. In 1978 standards were upgraded into the IEEE-488-1978 standards. The Model 595 conforms to these standards.

4.2 SHORTCUT TO IEEE-488 OPERATION

The information in this paragraph is intended to provide immediate hands-on experience in bus operation using the HP-85 computer with some of the most often used commands.

In general, IEEE-488 bus operation consists of connecting the instrument to the bus, setting the IEEE-488 address, and then programming the instrument to listen and/or talk. Perform the following procedure to get started using the Model 595 over the IEEE-488 bus:

1. Bus Connections
   A. Install the HP 82937A GPIB interface and an I/O ROM in the HP-85.
   B. Connect the GPIB interface of the computer to the IEEE-488 connector on the rear panel of the Model 595.

   Note: Complete information on bus connections is contained in paragraph 4.3.
2. Primary Address Selection—The primary address of the Model 595 is factory set to 28. If the instrument is currently set to a different address, change it back to 28. The current address can be checked and changed with the front panel IEEE-488 address program.

   Note: The detailed procedure for address selection is contained in paragaph 4.4.
3. Programming the Model 595 to Listen—Enter the following statements into the computer to place the instrument in the capacitance function. Make sure to press the END LINE key after each line is typed.

```
REMOTE 728
OUTPUT 728;"F0X"
```

   When END LINE is pressed the first time, the instrument will be placed in the remote, listen state by the REMOTE command. The instrument is identified by the number 728; where 7 is the controller's interface select code and 28 is the address of the Model 595. When END LINE is pressed the second time, the OUTPUT command will instruct the instrument to go to the capacitance function (F0X command).
4. Programming the Model 595 to Talk—Enter the following statements to instruct the instrument to output a reading over the bus to the computer:

```
DIM A$[50]
ENTER 728;A$
DISP A$
```

   When END LINE is pressed the first time, the computer will dimension (DIM) an array (A$) that will allow all 37 characters of the reading to be recognized. Normally, the computer will only recognize 18 characters at a time. When END LINE is pressed the second time, the ENTER command will instruct the instrument to send a reading to the computer. When END LINE is pressed the third time the reading will be displayed on the computer CRT.

4.3 BUS CONNECTIONS

The following paragraphs provide the detailed information needed to connect instrumentation to the IEEE-488 bus.

4.3.1 Typical Controlled Systems

System configurations are as varied as their applications. To obtain as much versatility as possible, the IEEE-488 bus was designed so that additional instrumentation could be easily added. Because of this versatility, system complexity can range from very simple to extremely complex.

Figure 4-1 shows two possible system configurations. Figure 4-1(A) shows the simplest possible controlled system. The controller is used to send commands to the instrument, which sends data back to the controller.

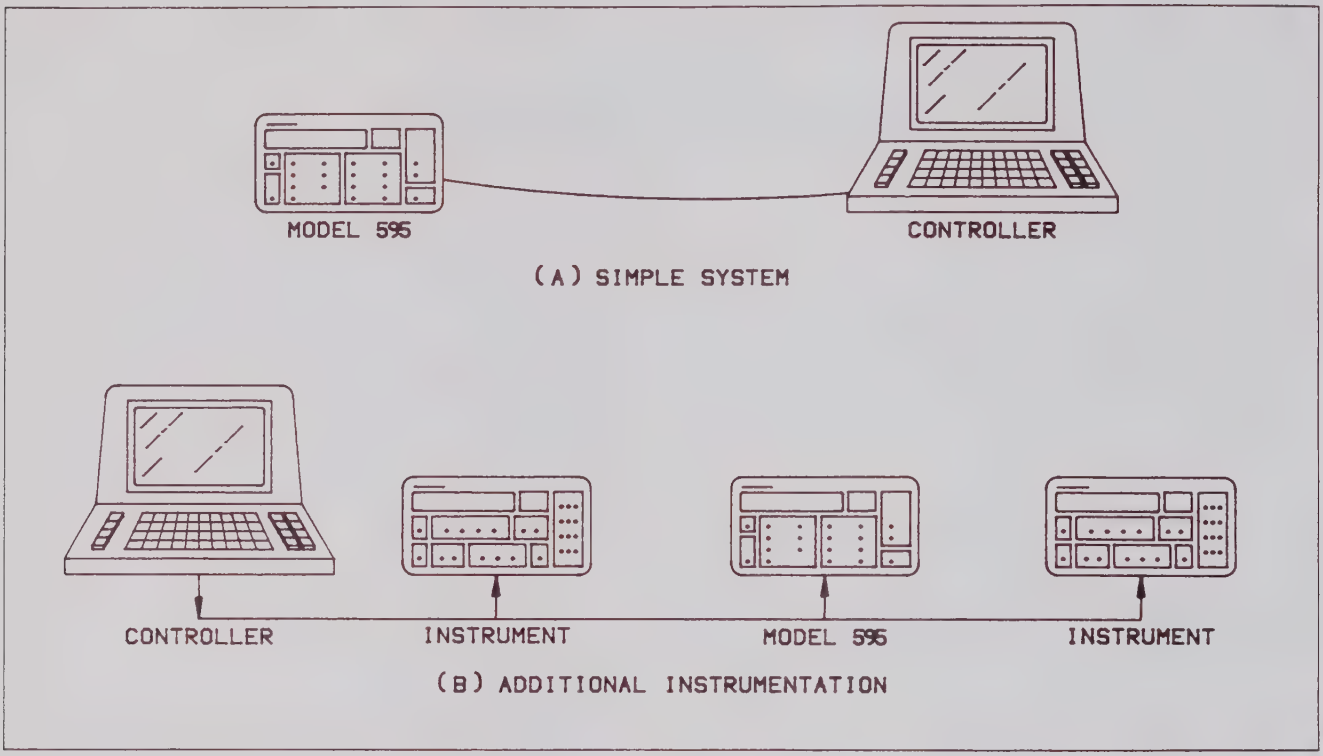


Figure 4-1. System Types

The system in Figure 4-1(B) is somewhat more complex since additional instruments are used. Depending on programming, all data may be routed through the controller or sent directly from one instrument to another.

4.3.2 Cable Connections

The Model 595 is to be connected to the IEEE-488 bus through a cable equipped with standard IEEE-488 connectors (shown in Figure 4-2). The connector is designed to be stacked to allow a number of parallel connections. Two screws are located on each connector to ensure that connections remain secure. Current standards call for metric threads, as identified by dark colored screws. Earlier versions had different screws, which are silver colored. Do not attempt to use these types of connectors with the Model 595 which is designed for metric threads.

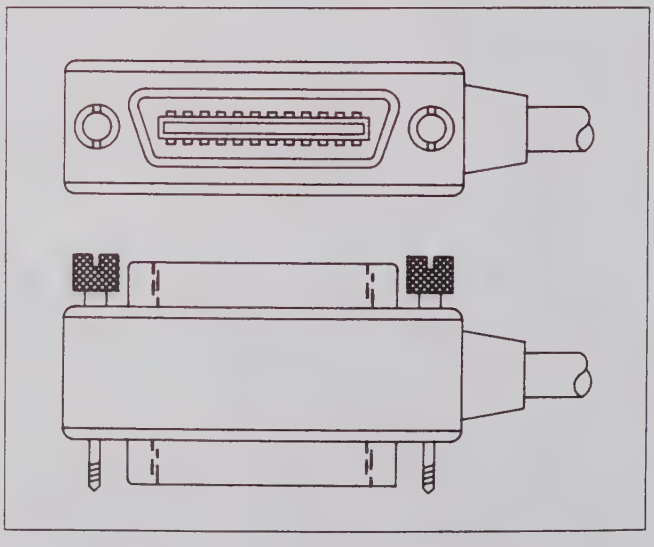


Figure 4-2. IEEE-488 Connector

A typical connecting scheme for the bus is shown in Figure 4-3.

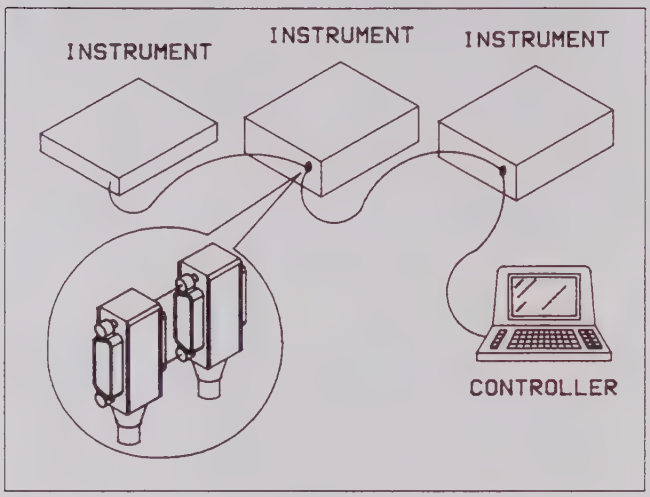


Figure 4-3. IEEE-488 Connections

NOTE

To avoid possible damage, do not stack more than three connectors on any one instrument.

Connect the Model 595 to the cable as follows:

1. Line up the connector on the cable with the connector on the rear panel of the instrument. Figure 4-4 shows the IEEE-488 connector.
2. Tighten the screws securely, but do not overtighten them.
3. Add additional connectors from other instruments as required.
4. Make sure the other end of the cable is properly connected to the controller. Some controllers have an IEEE-488 type connector while others do not. Consult the instruction manual of your controller for the proper connecting method.

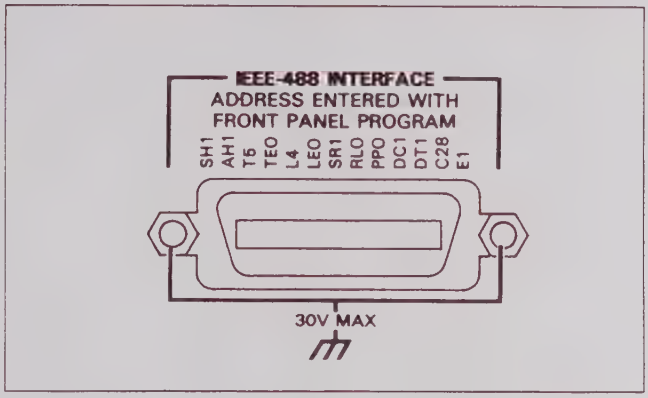


Figure 4-4. Model 595 Rear Panel IEEE-488 Connector

NOTE

The IEEE-488 bus is limited to a maximum of 15 devices, including the controller. Also, the maximum cable length is limited to 20 meters, or two meters times the number of devices, whichever is less. Failure to observe these limits may result in erratic bus operation.

Custom cables may be constructed by using the information in Table 4-1 and Figure 4-5. Table 4-1 lists the contact assignments for the various bus lines, while Figure 4-5 shows contact assignments.

Table 4-1. IEEE-488 Contact Designation

Number	Contact Designation	IEEE-488 Type
1	DIO1	Data
2	DIO2	Data
3	DIO3	Data
4	DIO4	Data
5	EOI (24)*	Management
6	DAV	Handshake
7	NRFD	Handshake
8	NDAC	Handshake
9	IFC	Management
10	SRQ	Management
11	ATN	Management
12	SHIELD	Ground
13	DIO5	Data
14	DIO6	Data
15	DIO7	Data
16	DIO8	Data
17	REN (24)*	Management
18	Gnd, (6)*	Ground
19	Gnd, (7)*	Ground
20	Gnd, (8)*	Ground
21	Gnd, (9)*	Ground
22	Gnd, (10)*	Ground
23	Gnd, (11)*	Ground
24	Gnd, LOGIC	Ground

*Number in parenthesis refer to signal ground return of reference contact number. EOI and REN signal lines return on contact 24.

CAUTION

The voltage between IEEE-488 common and chassis ground must not exceed 30V or instrument damage may occur.

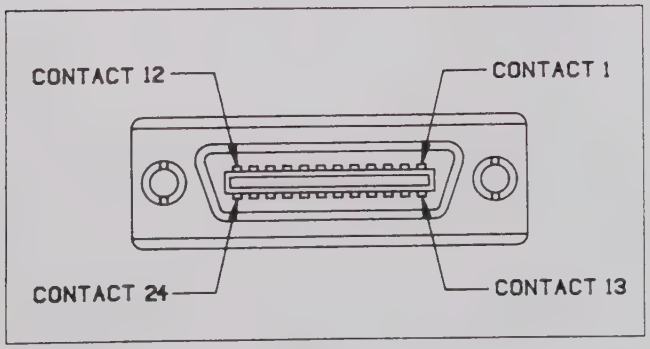


Figure 4-5. Contact Assignments

4.4 PRIMARY ADDRESS PROGRAMMING

The Model 595 must receive a listen command before it will respond to addressed commands. Similarly, the unit must receive a talk command before it will transmit its data. The Model 595 is shipped from the factory with a programmed primary address of 28. Until you become more familiar with your instrument, it is recommended that you leave the address at this value because the programming examples included in this manual assume that address.

The primary address may be set to any value between 0 and 30 as long as address conflicts with other instruments and the controller are avoided. Note that controllers are also given a primary address, so you must be careful not to use that address either. Whatever primary address you choose, make certain that it corresponds with the value specified as part of the controller's programming language.

To check the present primary address or to change to a new one, perform the following procedure:

1. Press the PROGRAM MENU button until the current IEEE-488 address is displayed. For example, if the current address is 28, the following message will be displayed:

   IEEE 28

2. To change the address, use the voltage source ADJUST buttons. The ▲ button increases the address value, while the ▼ button decreases the address value. See note 2 below.
3. To leave the program, press SHIFT, then the EXIT button.

NOTES:

1. Each device on the bus must have a unique primary address. Failure to observe this precaution will probably result in erratic bus operation.
2. The Model 595 may be placed in talk only (select address 40, 41, 42, 43) and may be used with a device such as a printer. When in talk only, the instrument takes control of the bus. No bus controller should be on the bus at this time. Paragraph 4-11 provides the complete procedure for using the instrument in the talk only mode.

4.5 INTERFACE FUNCTION CODES

The interface function codes, which are part of the IEEE-488-1978 standards, define an instrument's ability to

support various interface functions and should not be confused with programming commands found elsewhere in this manual. The interface function codes for the Model 595 are listed in Table 4-2. These codes are also listed for convenience on the rear panel adjacent to the IEEE-488 connector. The codes define Model 595 capabilities as follows:

SH (Source Handshake Function)—SH1 defines the ability of the instrument to initiate the transfer of message/data over the data bus.

AH (Acceptor Handshake Function)—AH1 defines the ability of the instrument to guarantee proper reception of message/data transmitted over the data bus.

T (Talker Function)—The ability of the instrument to send data over the bus to other devices is provided by the T function (T5). Instrument talker capabilities exist only after the instrument has been addressed to talk, or when it has been placed in talk only.

L (Listener Function)—The ability for the instrument to receive device-dependent data over the bus from other devices is provided by the L function (L4). Listener capabilities of the instrument exist only after it has been addressed to listen.

SR (Service Request Function)—SR1 defines the ability of the instrument to request service from the controller.

RL (Remote-Local Function)—The RL function defines the ability of the instrument to be placed in remote or local. While the instrument is in remote, the front panel controls are functional unless LLO (local lockout) has been asserted.

PP (Parallel Poll Function)—The instrument does not have parallel polling capabilities (PP0).

DC (Device Clear Function)—DC1 defines the ability of the instrument to be cleared (initialized).

DT (Device Trigger Function)—The ability for the instrument to have its readings triggered is provided by DT1.

C (Controller Function)—The instrument has some controller capabilities (C28).

TE (Extended Talker Function)—The instrument does not have extended talker capabilities (TE0).

LE (Extended Listener Function)—The instrument does not have extended listener capabilities (LE0).

E (Bus Driver Type)—The instrument has open-collector bus drivers (E1).

Table 4-2. Model 595 Interface Function Codes

Code	Interface Function
SH1	Source Handshake capability
AH1	Acceptor Handshake capability
T5	Talker (basic talker, serial poll, unaddressed to talk on LAG)
L4	Listener (basic listener, unaddressed to listen on TAG)
SR1	Service Request capability
RL0	Some Remote/Local capability
PP0	No Parallel Poll capability
DC1	Device Clear capability
DT1	Device Trigger capability
C28	Some Controller capability
E1	Open Collector Bus Drivers
TE0	No Extended Talker capabilities
LE0	No Extended Listener capabilities

4.6 CONTROLLER PROGRAMMING

There are a number of IEEE-488 controllers available, each with its own programming language. Also, different instruments have differing capabilities. In this section, we will discuss programming languages for HP-85. In addition, interface function codes that define Model 595 capabilities will be discussed.

NOTE
Controller programming information for using the IBM-PC interfaced through a Keithley Model 8573A IEEE-488 interface is located in Appendix D. See Appendix E for other controller programs.

4.6.1 Controller Handler Software

Before a specific controller can be used over the IEEE-488 bus, it must have IEEE-488 handler software installed. With some controllers, the software is located in ROM, and no software initialization is required on the part of the user. With other controllers, software must be loaded from disk or tape and be properly initialized. With the HP-85, for example, an additional I/O ROM that handles interface functions must be installed.

Other small computers that can be used as IEEE-488 controllers may have limited capabilities. With some, interface programming functions may depend on the interface being used. Often little software "tricks" are required to obtain the desired results.

From the preceding discussion, the message is clear: make sure the proper software is being used with the interface. Often, the user may incorrectly suspect that the hardware is causing a problem when it was the software all along.

4.6.2 Interface BASIC Programming Statements

The programming instructions covered in this section use examples written with Hewlett Packard Model 85 BASIC. This computer was chosen for these examples because of its versatility in controlling the IEEE-488 bus. This section covers those HP-85 statements that are essential to Model 595 operation.

A partial list of HP-85 statements is shown in Table 4-3. HP-85 statements have a one or three digit argument that must be specified as part of the statement. The first digit is the controller interface select code, which is set to 7 at the factory. The last two digits of those statements, requiring a 3-digit argument, specify the primary address.

Table 4-3. BASIC Statements Necessary to Send Bus Commands

Action	HP-85 Statement
Transmit string to device 28.	OUTPUT 728;A$
Obtain string from device 28.	ENTER 728;A$
Send GTL to device 28.	LOCAL 728
Send SDC to device 28.	CLEAR 728
Send DCL to all devices.	CLEAR 7
Send Remote Enable.	REMOTE 7
Cancel Remote Enable.	LOCAL 7
Serial poll device 28.	SPOLL (728)
Send Local Lockout.	LOCAL LOCKOUT
Send GET to device.	TRIGGER 728
Send IFC	ABORTIO 7

Those statements with a 3-digit argument listed in the table show a primary address of 28 (the factory default primary address of the Model 595). For a different address, you would, of course, change the last two digits to the required value. For example, to send a GTL command to a device using a primary address of 22, the following statement would be used: LOCAL 722.

Some of the statements have two forms; the exact configuration depends on the command to be sent over the bus. For example, CLEAR 7 sends a DCL command to all devices on the bus, while CLEAR 728 sends the SDC command to a device with a primary address of 28.

4.7 FRONT PANEL ASPECTS OF IEEE-488 OPERATION

The Model 595 has a number of front panel messages, associated with IEEE-488 programming. These messages, which are intended to inform you of certain conditions that occur when sending device-dependent commands to the instrument, are listed in Table 4-4 and are described in the following paragraphs.

Table 4-4. IEEE-488 Front Panel Messages

Message	Description
"bErr"	"Bus error" no remote, IDDC, IDDCO
"tErr"	Trigger Overrun
"nErr"	Number (A, H, L, V) or Conflict (Q, C)
"triG"	Waiting for trigger
Blank Digits	Triggered; reading will be displayed after the measurement conversion.

Another front panel aspect of bus operation is that the front panel controls are functional unless the LLO (local lockout) command was asserted. See paragraph 4.8.3 for more information on LLO.

4.7.1 Bus Errors

A bus error will occur if the instrument receives a device dependent command when it is not in remote, or if an illegal device-dependent command (IDDC) or illegal device-dependent command option (IDDCO) is sent to the instrument. Under these conditions, the complete command string will be rejected and the following bus error message will be displayed:

bErr

The U1 error status word must be read to determine the nature of the bus error (see paragraph 4.9.23). Also, the instrument can be programmed to generate an SRQ under these conditions (see paragraph 4.9.20).

A no remote error can occur when a command is sent to the instrument when the REN line is false. Note that the state of REN is only tested when the X character is received. An IDDC error can occur when an Illegal Device-Dependent Command such as E1X is received by the Model 595 (this command is invalid because the instrument has no command associated with that letter). Similarly, an IDDCO error occurs when an Illegal Device-Dependent

mand option is received. For example, the command T9X has an invalid option because the instrument has no such trigger mode.

HP-85 Programming Example—To demonstrate a bus error, send an IDDC with the following statements:

```
REMOTE 728
OUTPUT 714;"E1X"
```

When the second statement is executed, the bus error message appears on the display for about one second.

4.7.2 Trigger Overrun Error

A trigger overrun error occurs when the instrument receives a trigger while it is making a measurement conversion. Note that only the overrun triggers are ignored and will have no effect on the instrument except to generate the message below. When a trigger overrun occurs, the following front panel message will be displayed for approximately one second:

tErr

The instrument can be programmed to generate an SRQ when a trigger overrun occurs (see paragraph 4.9.20). Also, the TRIGGER OVERRUN bit in the U1 status word will be set when the error occurs (see paragraph 4.9.23).

HP-85 Programming Example—To demonstrate a trigger overrun error, enter the following statements into the HP-85 keyboard:

```
REMOTE 728
OUTPUT 728;"T3X"
TRIGGER 728 @ TRIGGER 728
```

Note that the trigger overrun message is displayed when the third statement is executed.

4.7.3 Number and Conflict Errors

A front panel error message is used to flag a number error or conflict error. A number error occurs when an out of range calibration value (A) or voltage source value (V, H, L) is sent over the bus. A conflict error occurs when the Q or C command is sent while the instrument is in the current function (F1). A number or conflict error will cause the command to be ignored (but not the entire string if all else is legal) and the following message will be displayed briefly:

nErr

The instrument can be programmed to generate an SRQ when a number or conflict error occurs (see paragraph 4.9.20). Also, the NUMBER and CONFLICT bits in the U1 error status word will be set when the appropriate error occurs (see paragraph 4.9.23).

HP-85 Programming Example—To demonstrate a number error, enter the following statements into the computer:

```
REMOTE 728
OUTPUT 728;"U21X"
```

When END LINE is pressed the second time, a number error will occur because the voltage source cannot be set to 21V.

4.7.4 Waiting for Trigger

When a trigger command (TnX) is sent over the bus, the instrument will stop making measurements and display the "waiting for trigger" message. The decimal point, and range/function mnemonics or exponent are also displayed to define the present operating state. For example, with the instrument on the 20nF range, sending T3 over the bus will result with one of the following messages being displayed:

t.riG nF
or
.triG -8

When the voltage source is set for off, DC or square-wave output, measurements will continue when the required trigger occurs. If a trigger command is sent while a staircase is in process, the voltage source will set to a DC output. To continue the staircase output, first set the voltage source for a staircase output (W3) and then apply the required trigger. See paragraph 4.9.19 for detailed information on triggers.

HP-85 Programming Example—Enter the following statements into the computer to demonstrate the "waiting for trigger" message when the instrument is placed in one-shot, triggered by GET.

```
REMOTE 728
OUTPUT 728;"T3X"
```

When END LINE is pressed the second time the instrument will display the "waiting for trigger" message. Send the following GET command to trigger a reading and cancel the message:

```
TRIGGER 728
```

The display will be blank for the period of the measurement conversion.

4.8. GENERAL BUS COMMANDS

General bus commands are those commands such as DCL that have the same general meaning regardless of the instrument type. Commands supported by the Model 595 are listed in Table 4-5, which also lists HP-85 statements necessary to send each command. Note that commands requiring that a primary address be specified assume that the Model 595 primary address is set to 28 (its default address).

4.8.1 REN (Remote Enable)

The remote enable command is sent to the Model 595 by the controller to set up the instrument for remote operation. Generally, the instrument should be placed in remote before programming it over the bus. Simply setting REN true will not actually place the instrument in remote. The instrument must be addressed after setting REN true before it will go into remote.

To place the Model 595 in remote, the controller must perform the following sequence:

1. Set the REN line true.
2. Address the instrument to listen.

HP-85 Programming Example—This sequence is automatically performed by the HP-85 when the following is typed in at the keyboard.

```
REMOTE 728
```

After the END LINE key is pressed, the instrument will be in remote, as indicated by the REMOTE and LISTEN lights. If not, check to see that the instrument is set to the proper primary address (28), and that the bus connections are properly made.

4.8.2 IFC (Interface Clear)

The IFC command is sent by the controller to place the Model 595 in the local, talker and listener idle states. The unit will respond to the IFC command by cancelling front panel TALK or LISTEN lights if the instrument was previously placed in one of those states.

To send the IFC command, the controller need only set the IFC line true for a minimum of 100μsec.

Table 4-5. General Bus Commands and Associated BASIC Statements

Command	HP-85 Statement	Affect On Model 595
REN	REMOTE 7	Goes into remote when next addressed
IFC	ABORTIO 7	Goes into talker and listener idle states
LLO	LOCAL LOCKOUT 7	Front panel controls locked out
GTL	LOCAL 728	Cancel remote
DCL	CLEAR 7	Returns to default conditions
SDC	CLEAR 728	Returns to default conditions
GET	TRIGGER 728	Triggers reading in T2 and T3
	LOCAL 7	Cancel LLO

HP-85 Programming Example—Before demonstrating the IFC command, turn on the TALK indicator with the following statements:

```
REMOTE 728
ENTER 728;A$
```

At this point, the REMOTE and TALK lights should be on. The IFC command can be sent by typing the following statement on the HP-85:

```
ABORTIO 7
```

After the END LINE key is pressed, the REMOTE and TALK lights will turn off, indicating that the instrument has gone into the talker idle state.

4.8.3 LLO (Local Lockout)

The LLO command is used to remove the instrument from local operation. After the unit receives LLO, all its front panel controls except POWER will be inoperative. REN must be true for the instrument to respond to LLO. REN must be set false to cancel LLO.

To send the LLO command, the controller must perform the following steps:

1. Set ATN true.
2. Place the LLO command on the data bus.

HP-85 Programming Example—The LLO command is sent by using the following HP-85 statement:

```
REMOTE 7
LOCAL LOCKOUT 7
```

After the second statement is entered, the instrument's front panel controls will be locked out.

4.8.4 GTL (Go To Local) and Local

The GTL command is used to take the instrument out of remote. With some instruments, GTL may also cancel LLO. With the Model 595, however, REN must first be set false before LLO will be cancelled.

To send GTL, the controller must perform the following sequence:

1. Set ATN true.
2. Address the instrument to listen.
3. Place the GTL command on the bus.

HP-85 Programming Example—Place the instrument in the remote mode with the following statement:

```
REMOTE 728
```

Now send GTL with the following statement:

```
LOCAL 728
```

When the END LINE key is pressed, the front panel REMOTE indicator goes off, and the instrument goes into the local mode. To cancel LLO, send the following:

```
LOCAL 7
```

4.8.5 DCL (Device Clear)

The DCL command may be used to clear the Model 595 and return it to its power-up default conditions. Note that the DCL command is not an addressed command, so all instruments equipped to implement DCL will do so simultaneously. When the Model 595 receives a DCL command, it will return to the power-up default conditions.

To send the DCL command, the controller must perform the following steps:

1. Set ATN true.
2. Place the DCL command byte on the data bus.

HP-85 Programming Example—Place the unit in an operating state that is not a power-up default condition. Now enter the following statement into the HP-85 keyboard:

```
CLEAR 7
```

When the END LINE key is pressed, the instrument returns to the power-up default conditions.

4.8.6 SDC (Selected Device Clear)

The SDC command is an addressed command that performs essentially the same function as the DCL command. However, since each device must be individually addressed, the SDC command provides a method to clear only a single, selected instrument instead of clearing all instruments simultaneously, as is the case with DCL. When the Model 595 receives the SDC command, it will return to the power-up default conditions.

To transmit the SDC command, the controller must perform the following steps:

1. Set ATN true.
2. Address the Model 595 to listen.
3. Place the SDC command on the data bus.

HP-85 Programming Example—Place the unit in an operating state that is not a power-up default condition. Now enter the following statement into the HP-85 keyboard:

```
CLEAR 728
```

After END LINE is pressed, the instrument returns to the power-up default conditions.

4.8.7 GET (Group Execute Trigger)

GET may be used to trigger the Model 595 to take readings if the instrument is placed in the appropriate trigger (more information on triggers may be found in paragraph 4.9.19).

To send GET, the controller must perform the following steps:

1. Set ATN true.
2. Address the Model 595 to listen.
3. Place the GET command byte on the data bus.

HP-85 Programming Example—Type the following statements into the HP-85 keyboard to place the instrument in remote and enable the correct trigger for this demonstration:

```
REMOTE 728
OUTPUT 728;"T3X"
```

Now send the GET command with the following statement:

```
TRIGGER 728
```

When the END LINE key is pressed, the instrument will process a single reading.

4.8.8 SPE, SPD (Serial Polling)

The serial polling sequence is used to obtain the Model 595 serial poll byte. The serial poll byte contains important information about internal functions, as described in paragraph 4.9.20. Generally, the serial polling sequence is used by the controller to determine which of several instruments has requested service with the SRQ line. However, the serial polling sequence may be performed at any time to obtain the serial poll byte from the Model 595.

The serial polling sequence is conducted as follows:

1. The controller sets ATN true.
2. The controller then places the SPE (Serial Poll Enable) command byte on the data bus. At this point, all active devices are in serial poll and are waiting to be addressed.
3. The Model 595 is then addressed to talk.
4. The controller sets ATN false.
5. The instrument then places its serial poll byte on the data bus, at which point it is read by the controller.
6. The controller then sets ATN true and places the SPD (Serial Poll Disable) command byte on the data bus to end the serial polling sequence.

Once instruments are in serial poll, steps 3 through 5 above can be repeated by sending the correct talk address for each instrument. ATN must be true when the address is transmitted and false when the status byte is read.

HP-85 Programming Example—The HP-85 SPOLL statement automatically performs the sequence just described. To demonstrate serial polling, type in the following statements into the HP-85:

```
REMOTE 728
S=SPOLL (728)
DISP S
```

When the END LINE key is pressed the second time, the computer conducts the serial polling sequence. The decimal value of the serial poll byte is then displayed on the computer CRT when the END LINE key is pressed the third time. More information on serial polling can be found in paragraph 4.9.20.

4.9 DEVICE-DEPENDENT COMMANDS

This section contains the information needed to control the Model 595 over the IEEE-488 bus using the device-dependent commands. A programming example using the HP-85 computer is included for each device-dependent command.

It is assumed that the user is already familiar with front panel operation.

4.9.1 Programming Overview

IEEE-488 device-dependent commands (summarized in Table 4-6) are used with the Model 595 to control various operations including function, range and trigger. Each command is made up of a single ASCII letter followed by a number representing an option of that command. The number may be in either an integer, decimal or exponential format. For example, a command to control the measuring function is programmed by sending an ASCII "F" followed by a number representing the function option. The IEEE-488 bus treats these commands as data in that ATN is false when the commands are transmitted.

A number of commands may be grouped together in one string. A command string is usually terminated with an ASCII "X" character, which tells the instrument to execute the command string. Commands sent without the execute character will not be executed at that time, but they will be retained within an internal command buffer for execution at the time the X character is received. If any errors occur, the instrument will display appropriate front panel error messages and generate an SRQ if programmed to do so when "X" is received.

Bus commands affect the Model 595 much like the front panel controls. Note that commands are not necessarily executed in the order received. Thus, to force a particular command sequence, you would follow each command with the execute character (X), as in the example string, Z1XF1X, which will first enable ZERO CHECK and then select the CURRENT function. If a particular command occurs n times in a command string, then the "nth" occurrence is the only one used, i.e., R5R4R3X goes to R3X only.

Device-dependent commands can be sent either one at a time, or in groups of several commands within a single string. Some examples of valid command strings include:

F0X—Single command string.
F0R4D0X—Multiple command string.
T6 X—Spaces are ignored.

Typical invalid command strings include:

B1X—Invalid command, as B is not one of the instrument commands. (IDDC)
F2X—Invalid command option because 2 is not an option of the F command. (IDDCO)

If an illegal device-dependent command (IDDC) or an illegal device-dependent command option (IDDCO) is received, or if a command string is sent with REN false, the string will be ignored and "bErr" (bus error) will be displayed.

NOTE

Programming examples assume that the Model 595 is at its factory default value of 28.

In order to send a device-dependent command, the controller must perform the following steps:

1. Set ATN true.
2. Address the Model 595 to listen.
3. Set ATN false.
4. Send the command string over the bus one byte at a time.

NOTE

REN must be true when sending device-dependent commands to the instrument, or it will ignore the command and display a bus error message.

General HP-85 Programming Example—Device-dependent commands may be sent from the HP-85 with the following statement:

```
A$ = ''F1R4Z0X''
OUTPUT 728;A$
```

A$ in this case contains the ASCII characters representing the command string.

Table 4-6. Device-Dependent Command Summary

Mode	Command	Description	Paragraph
Execute	X	Execute device-dependent commands received since last "X"	4.9.2
METER BLOCK COMMANDS			
Display	D0* D1 D2 D3 D4 D5	Meter Voltage source High limit of voltage source Low limit of voltage source Step voltage Delay time	4.9.3
Function†	F0* F1	Capacitance Current	4.9.4
Range†	 R1 R2 R3* R4 R5 R6 R7 R8	Capacitance (F0) / Current (F1) 200pF / 20pA 2nF / 200pA 20nF / 2nA 20nA 200nA 2μA 20μA 200μA	4.9.5
Zero Check†	Z0 Z1* Z2	Zero check off Zero check on Zero check on and zero corrected	4.9.6
Suppress	N0* N1	Suppress off Suppress on using new value	4.9.7
Filter†	P0* P1 P2 P3	Filter off Filter 1 Filter 2 Filter 3 (DC measurements)	4.9.8
VOLTAGE SOURCE COMMANDS			
High Limit†	Hnn.nn H20*	Set high limit of voltage source; where nn.nn = −20.00V to 20.00V	4.9.9
Low Limit†	Lnn.nn L−20*	Set low limit of voltage source; where nn.nn = −20.00V to 20.00V	4.9.10
Voltage Source†	Vnn.nn V0*	Set voltage source bias level; where nn.nn = LO value to HI value	4.9.11
Step Voltage†	S0 S1 S2* S3 S4 S5 S6 S7	10mV step 20mV step 50mV step 100mV step −10mV step −20mV step −50mV step −100mV step	4.9.12

Table 4-6. Device-Dependent Command Summary (Cont.)

Mode	Command	Description	Paragraph
Delay Time†	Innn.nn I.07*	Set delay time for staircase and square wave; where nnn.nn = 000.07sec to 199.99sec	4.9.13
WAVEFORM COMMANDS			
Waveform	W0 W1 W2* W3	Voltage source off (0.0 volts) DC output (voltage source level) Square-wave output (voltage source + Vstep) Staircase output (voltage source + Vstep)	4.9.14
READING/OUTPUT COMMANDS			
C/C_o	C0* C1 C2	Capacitance normalization off Capacitance normalization on Take new C_o value	4.9.15
Capacitance Modifiers‡	Q0* Q1 Q2 Q3	Capacitance displayed, not corrected Q/t displayed, capacitance not corrected Capacitance displayed, capacitance corrected Q/t displayed, capacitance corrected	4.9.16
Prefixes	 G0 G1 G2 G3 G4 G5 G6 G7	TERMINATE ON EACH READING 0 = Reading; prefix 1 = Reading; no prefix 2 = Plotter; prefix 3 = Plotter; no prefix TERMINATE ON EACH NON-STAIRCASE READING 4 = Reading; prefix 5 = Reading; no prefix 6 = Plotter; prefix 7 = Plotter; no prefix	4.9.17
Analog Output	O0* O1 O2 O3 O4 O5 O6 O7	Autopen, X1 gain Pen up, X1 gain Pen down, X1 gain Same as O1 Autopen, X10 gain Pen up, X10 gain Pen down, X10 gain Same as O4	4.9.18
BUS CONTROL COMMANDS			
Triggers†	T0 T1 T2 T3 T4 T5 T6* T7	Continuous, triggered by Talk One-shot, triggered by Talk Continuous, triggered by GET One-shot, triggered by GET Continuous, triggered by X One-shot, triggered by X Continuous, triggered by External Trigger One-shot, triggered by External Trigger	4.9.19

Table 4-6. Device-Dependent Command Summary (Cont.)

Mode	Command	Description	Paragraph
SRQ Mask	M0* M1 M2 M4 M8 M16 M32	Clear SRQ mask Reading overflow Not used Staircase done Reading done Ready Error	4.9.20
EOI and Bus Hold-off	K0* K1 K2 K3	Send EOI, hold off on X Do not send EOI, hold off on X Send EOI, do not hold off on X Do not send EOI, do not hold off on X	4.9.21
Terminator	Y0* Y1 Y2 Y3 Y4	CR LF LF CR CR LF No terminator	4.9.22
STATUS COMMANDS			
Digital Calibration	Annn.nnE-nn	Calibration value using exponent	4.9.24
Self-Test and NVRAM Storage	J0 J1-J18 J19	Perform self-test No operation Store calibration constants in permanent memory	4.9.25
Status	U0 U1 U2 U3 U4 U5	Send machine status word Send error status word Send data status word Send delay time Send high and low limits of voltage source Send voltage source level	4.9.23

* DEFAULT VALUE (on power up or after receiving DCL or SDC command).

† If in staircase, waveform will change to DC (pause)

‡ Only changing capacitance correction will cause waveform to change to DC.

Note: If a measurement is changed to DC, the output voltage is moved to the next level where the effective step is off in order to preserve the direction of the measurement.

4.9.2 Execute (X)

Purpose Directs the Model 595 to execute device-dependent commands received since previous "X".

Format X

Description The execute command is implemented by sending an ASCII "X" over the bus. Usually, the execute character is the last byte in the command string (a number of commands may be grouped together into one string); however, there may be certain circumstances where it is desirable to send a command string at one time, and then send the execute character later on. Command strings sent without the execute character will be stored within an internal command buffer for later execution. When the X character is finally transmitted, the stored commands will be executed, assuming that all commands in the previous string were valid. If multiple Xs are in one string, the sequence will be forced in that order (i.e., C2XC1X to store and normalize).

Example Enter the following statements into the HP-85 keyboard:

```
REMOTE 728
OUTPUT 728;''F1X''
OUTPUT 728;''F0X''
OUTPUT 728;''X''
```

When the END LINE key is pressed the second time, the instrument is put in the current function. The next statement puts the instrument in the capacitance function. Note that the instrument remains in the listener active state after the commands are transmitted.

4.9.3 Display (D)

Purpose Determines the Model 595 data displayed on the front panel.

Format **Dn**

Parameters
n = 0 Meter
n = 1 Voltage Source
n = 2 High Limit of Voltage Source
n = 3 Low Limit of Voltage Source
n = 4 Step Voltage
n = 5 Delay Time

Description The instrument can be programmed to display capacitance/current measurements, the voltage source value, the high or low limit settings of the voltage source, the selected step voltage, or the delay time setting.

Default Upon power up or after receiving a DCL or SDC command, the instrument will be in D0.

Reference In general, the equivalent front panel controls for the D command are the LIMITs, STEP V, DELAY TIME and DISPLAY SOURCE buttons. See paragraphs 3.3.7 through 3.3.10 for front panel control of the display.

Example From the front panel, press the CURRENT or CAPACITANCE button. To display the high limit of the voltage source, enter the following program statements into the computer:

```
REMOTE 728
OUTPUT 728;''D2X''
OUTPUT 728;''D0X''
```

When END LINE is pressed the second time, the high limit of the voltage source will be displayed. The last statement returns the instrument to the meter display.

4.9.4 Function (F)

Purpose Selects the measurement function of the instrument.

Format **Fn**

Parameters n = 0 Capacitance
n = 1 Current

Description Allows the user to select the type of measurement (capacitance or current) made by the Model 595. When the instrument responds to a function command, it will be ready to take a reading. When in F0 (capacitance function), both the capacitance and Q/t readings are sent over the bus when the instrument is addressed to talk.

Default Upon power up or after receiving a DCL or SDC command, the instrument will be in F0.

Reference The equivalent front panel controls for the F command are the CURRENT and CAPACITANCE, Q/t buttons. See paragraphs 3.3.1 and 3.3.2 for complete information on front panel function control.

Example From the front panel, select the capacitance function. Enter the following statements into the computer to place the instrument in the current function:

```
REMOTE 728
OUTPUT 728;''F1X''
OUTPUT 728;''F0X''
```

After END LINE is pressed the second time, the instrument will go to current function. The third statement will put the instrument in the capacitance function.

NOTE: The Model 595 automatically limits the capacitance range number to 3.

4.9.5 Range (R)

Purpose To control the sensitivity (ranges) of the measurement functions.

Format **Rn**

Parameters

	Capacitance (F0)	Current (F1)
n = 1	200pF	20pA
n = 2	2nF	200pA
n = 3	20nF	2nA
n = 4		20nA
n = 5		200nA
n = 6		2μA
n = 7		20μA
n = 8		200μA

Description This command and its options perform essentially the same functions as the front panel RANGE buttons. The instrument will be ready to take a reading after the instrument makes a range change. The Model 595 automatically limits the capacitance range number to 3.

Default Upon power up or after receiving a DCL or SDC command, the instrument will be in R3.

Reference The equivalent front panel controls for the R command are the RANGE buttons. See paragraph 3.3.6 for information on front panel range control.

Example From the front panel, select the capacitance function and the 20nF range. Enter the following statements into the computer to place the instrument in the 200pF range:

```
REMOTE 728
OUTPUT 728;''F1R7X''
OUTPUT 728;''F0R2X''
```

After END LINE is pressed the second time, the instrument will be in the 200pF range. The last statement puts the instrument in the 2nF range.

NOTE: When n=4–8 on F0 (capacitance), the instrument will go to the R3 range (20nF).

4.9.6 Zero Check, Zero Correct (Z)

Purpose Use Zero Check as a standby mode whenever making changes to the measurement setup. Use Zero Correct when in the current function to cancel any internal offsets that might affect instrument accuracy. Zero Correct is most effective when taken on the 20pA range.

Format **Zn**

Parameters
n = 0 Zero Check off.
n = 1 Zero Check on.
n = 2 Zero Check on and Zero Corrected.

Description Zero Check (Z1) should be used whenever making changes to the measurement setup. This command places the instrument in a standby condition in which measurements cannot be made.

Zero Check and Correct (Z2) are used to cancel internal offsets when the instrument is in the current function. When Z2 is sent, the reading will zero (the Model 595 will subtract the offset from all subsequent readings). The correction value will be stored in permanent memory and reapplied upon power up. The Z2 command can be sent with the Zero Check on or off. Use the following procedure to zero the current function:

1. Select the current function and the 20pA range.
2. Turn on Zero Check (Z1) and observe the offset. Correct the offset by sending the Z2 command over the bus.
3. Disable Zero Check by sending Z0. Readings can then be taken in the usual manner.

Default Upon power up or after a DCL or SDC command is received, Zero Check (Z1) will be on.

Reference The equivalent front panel control for the Z command is the ZERO CHECK (CORRECT) button. See paragraph 3.3.5 for complete information on Zero Check.

Example From the front panel, select the 20pA current range and turn off Zero Check. Enter the following statements to zero the instrument:

```
REMOTE 728
OUTPUT 728;''Z2X''
OUTPUT 728;''Z0X''
```

After END LINE is pressed the second time, Zero Check will turn on and zero the instrument. The third statement returns the instrument to normal operation.

NOTE: Only the current function should be zeroed.

4.9.7 Suppress (N)

Purpose Serves as a means of baseline suppression by subtracting a stored offset value from subsequent readings.

Format **Nn**

Parameters
n = 0 Suppress off.
n = 1 Suppress on using new value.

Description When Suppress is enabled (N1), the instrument will store the next reading as the baseline value. All subsequent readings will be the difference between this stored baseline value and the actual capacitance or current measurement (applicable only to capacitance and current, even if Q/t is "on").

Suppress reduces the dynamic range of the measurement. For example, assume that 10nA is applied to the input of the instrument. If the stored baseline value is 10nA on the 20nA range, the display will read zero. In addition, input capacitance of −10nA would overrange the instrument, even though current measurements to −19.999nA are normally within the capabilities of the 20nA range.

To use Suppress, perform the following steps:

1. Cancel Suppress, if on, by sending N0 over the bus.
2. Select a range and function consistent with the expected measurement.
3. Connect the signal to be used as a baseline to the instrument input (perhaps the strays of an "opened" fixture).
4. Turn on Suppress by sending N1X over the bus and wait for the baseline to be stored.
5. Add the signal to be measured. Subsequent readings will be the difference between the baseline and the applied signal.

NOTE: If the instrument is waiting for a trigger ("triG" message displayed), sending N1 will turn on the SUPPRESS indicator light, but a baseline value cannot be stored until the proper trigger occurs. See paragraph 4.9.19 for trigger information.

Default Upon power up or after receiving a DCL or SDC command, Suppress will be off (N0).

Reference The equivalent front panel control for the N command is the the SUPPRESS button. See paragraph 3.3.4 for complete information on using Suppress.

Example From the front panel, turn off Suppress if it is on. Enter the following statements to turn Suppress on:

```
REMOTE 728
OUTPUT 728;''N1X''
OUTPUT 728;''N0X''
```

NOTE: After END LINE is pressed the second time, Suppress will turn on and blank the display. The last statement turns Suppress off. Setting the range lower than the stored baseline value may overrange the instrument since, for example, 10nA is overrange on the 2nA range. Function changes cancel baseline suppress.

4.9.8 Filter (P)

Purpose Use to control the internal filter of the Model 595.

Format **Pn**

Parameters
n = 0 Filter off
n = 1 Filter 1
n = 2 Filter 2
n = 3 Filter 3 (DC measurements)

Description Filtering is used to separate the reading from a noisy input signal. The P1 and P2 filters are used for changing inputs, i.e., inputs associated with CV or IV curves. The P2 filter provides more filtering, but may hinder reading response time. The P3 filter is used to filter non-changing input signals.

Default Upon power up or after a DCL or SDC command is received, the filter will be off (P0).

Reference From the front panel, filter is controlled by the FILt program. See paragraph 3.4.3 for details.

Example With the Model 595 in the capacitance function, enter the following statements into the computer to place the instrument in the P3 filter:

```
REMOTE 728
OUTPUT 728;''F1P3W1X''
OUTPUT 728;''P0X''
```

After END LINE is pressed the second time, the instrument will be in the current function with the third level filter enabled and the waveform set to DC. The last statement will turn off the filter when END LINE is pressed.

4.9.9 High Limit (H)

Purpose Use to set the high limit of the voltage source.

Format **Hnn.nn**

Parameters nn.nn = −20.00V to 20.00V

NOTE: Only as many significant digits as necessary need be sent (i.e. send H5 instead of H05.00 to program high limit to 5V).

Description The high limit value defines the highest voltage level to which the voltage source can be set. A positive-going staircase will stop at the high limit.

Default Upon power up or after a DCL or SDC command is received, the high limit will be set to 20.00V.

Reference The equivalent front panel control for the H command is the ▲ LIMIT button. See paragraph 3.3.7 for complete information on high limit.

Example Enter the following statements into the computer to set the high limit of the voltage source to +10V:

```
REMOTE 728
OUTPUT 728;"D2X"
OUTPUT 728;"H10X"
```

When END LINE is pressed the second time, the presently programmed high limit will be displayed. After END LINE is pressed the third time, the high limit will be reprogrammed to 10V and displayed.

4.9.10 Low Limit (L)

Purpose Use to set the low limit of the voltage source.

Format **Lnn.nn**

Parameters nn.nn = −20.00V to 20.00V

NOTE: Only as many significant digits as necessary need be sent (i.e. send L5 instead of L05.00 to program low limit to 5V).

Description The low limit value defines the lowest voltage level to which the voltage source can be set. A negative-going staircase will stop at the low limit.

Default Upon power up or after a DCL or SDC command is received, the low limit will be set to −20.00V.

Reference The equivalent front panel control for the L command is the ▼ LIMIT button. See paragraph 3.3.7 for complete information on low limit.

Example Enter the following statements into the computer to set a low limit of −10V:

```
REMOTE 728
OUTPUT 728;''D3X''
OUTPUT 728;''L-10X''
```

When END LINE is pressed the second time, the presently programmed low limit will be displayed. After END LINE is pressed the third time, the low limit will be reprogrammed to −10V.

4.9.11 Voltage Source (V)

Purpose Used to set the DC voltage level of the voltage source.

Format **Vnn.nn**

Parameters nn.nn=Low Level (L) to High Level (H)

NOTE: Only as many significant digits as necessary need be sent (i.e. send V4 in place of V04.00).

Description The range of the voltage source is from −20.00V to 20.00V. When making capacitance measurements, the square wave or staircase originates from the programmed DC voltage level. Note that the V command does not apply the programmed voltage level to the voltage source output connector. The output is controlled by the W (waveform) command (see paragraph 4.9.14).

Default Upon power up or after a DCL or SDC command is received, the voltage source will be programmed to 00.00V.

Reference The equivalent front panel controls for the V command are the DISPLAY SOURCE, ADJUST and +/− buttons. See paragraphs 3.3.10, 3.3.11 and 3.3.12, respectively for complete information on the voltage source.

Example Cycle power on the Model 595 and enter the following statements into the computer to set the voltage source to 15V:

```
REMOTE 728
OUTPUT 728;"D1X"
OUTPUT 728;"V15X"
```

After END LINE is pressed the second time, the present voltage source setting will be displayed. After END LINE is pressed the third time, the voltage source value will be programmed to 15V.

4.9.12 Step Voltage (S)

Purpose Use to set the step voltage magnitude of a square wave or staircase.

Format **Sn**

Parameters
n = 0 10mV step
n = 1 20mV step
n = 2 50mV step
n = 3 100mV step
n = 4 −10mV step
n = 5 −20mV step
n = 6 −50mV step
n = 7 −100mV step

Description The S command defines the magnitude and direction of each voltage step. This command applies to square wave and staircase waveforms.

Default Upon power up or after a DCL or SDC command is received, the step voltage will be 50mV (S2).

Reference The equivalent front panel controls for the S command are the STEP V, ADJUST and +/− buttons. See paragraph 3.3.8 for complete information on step voltage.

Example Enter the following statements into the computer to set the step voltage to 100mV:

```
REMOTE 728
OUTPUT 728;''D4X''
OUTPUT 728;''S3X''
```

When END LINE is pressed the second time the presently programmed step voltage will be displayed. When END LINE is pressed the third time, the step voltage will set to 100mV.

4.9.13 Delay Time (I)

Purpose Used to program the step-to-measurement delay time for a square wave or staircase waveform; or reading delay time for DC and OFF waveforms.

Format **Innn.nn**

Parameters nnn.nn = 000.07sec to 199.99sec

NOTE: Only as many significant digits as necessary need be sent (i.e. send I2 in place of I002.00).

Description The Model 595 displays readings which are calculated from input measurements. The measurements are taken after the delay time. The step time (regardless of output waveform) is the delay time +.04sec (see specification clarification at beginning of manual). Capacitance readings are displayed for every other step; current readings are displayed for each step. See Figure 3-3 for an illustration of delay time.

Default Upon power up or after a DCL or SDC command is received, the delay time will be set to 0.07 seconds (I.07).

Reference The equivalent front panel controls for the I command are the DELAY TIME and ADJUST buttons. See paragraph 3.3.10 for complete information on delay time.

Example Enter the following program statements into the computer to set a delay time of three seconds:

```
REMOTE 728
OUTPUT 728;''D5X''
OUTPUT 728;''I3X''
```

After END LINE is pressed the second time, the presently programmed delay time will be displayed. After END LINE is pressed the third time, the delay time will be three seconds.

4.9.14 Waveform (W)

Purpose Use to select the voltage source output waveform.

Format **Wn**

Parameters
n = 0 Off (0V)
n = 1 DC output
n = 2 Square-wave output
n = 3 Staircase output

Description When W0 is sent over the bus, 0V is present at the output of the voltage source.

When W1 is sent, a DC voltage, determined by the V command (see paragraph 4.9.11), is available at the output of the voltage source.

When W2 is sent, a voltage square wave is available at the output of the voltage source. The voltage level is determined by the V command (paragraph 4.9.11), the amplitude and step direction of the square wave are determined by the S command (paragraph 4.9.12) and the time duration of the step is determined by the I command plus .04sec (paragraph 4.9.13).

When W3 is sent, a voltage staircase is available at the output of the voltage source. The starting voltage level is determined by the V command, the amplitude and direction of each step of the staircase is determined by the S command and the time duration at each step is determined by the I command. When W3 is sent, the voltage level staircases to the limit of the voltage source (as determined by the H or L command) and stops. At this point the output of the voltage source becomes DC (W1).

Default Upon power up or after a DCL or SDC command is received, the voltage source will be sending a square wave (W2).

Reference The equivalent front panel controls for the W command are the WAVEFORM SELECT buttons. See paragraph 3.3.7 for information on controlling the output waveform of the voltage source from the front panel.

Example Cycle power on the Model 595 and press the DISPLAY SOURCE button to display the voltage source. Enter the following statements into the computer to staircase the voltage source:

```
REMOTE 728
OUTPUT 728;''W3X''
OUTPUT 728;''W1X''
OUTPUT 728;''W3X''
```

After END LINE is pressed the second time, the voltage source will staircase up to 20V and then stop. After END LINE is pressed the third time (before the staircase ends), the waveform will change to DC output. After END LINE is pressed the fourth time, the staircase output will continue.

4.9.15 C/C_o (C)

Purpose Use to compare capacitance measurements by normalizing the applied capacitance readings to a stored capacitance reading (C0).

Format Cn

Parameters
n = 0 C/C_o off
n = 1 C/C_o on
n = 2 Store new value of C_o

Description When C1 is sent, capacitance measurements will be divided by the stored capacitance reading (C_o). If there is no capacitance reading stored, the display will overrange (i.e., 2.360nF divided by 0 = undefined). When C2 is sent, the next capacitance reading will be stored as the C_o value.

Default Upon power up or after a DCL or SDC command is received, C/C_o will be off with no reading stored (C0).

Reference The equivalent front panel control for the C command is the C/C_o (STORE C_o) button. See paragraph 3.3.3 for complete information on C/C_o.

Example Place the instrument in the capacitance function and enter the following statements into the computer to store a value for C_o and then calculate C/C_o.

PROGRAM	COMMENTS
`10 DIM A$[50]`	
`20 REMOTE 728`	
`30 OUTPUT 728; ''C2X''`	Store next reading as C0
`40 ENTER 728; A$`	Obtain next reading
`50 DISP A$`	Display reading (C0)
`60 OUTPUT 728; ''C1X''`	Enable normalizing feature
`70 END`	

After the program is run, the next capacitance reading will be stored as C0 and displayed. The normalizing feature will then turn on.

NOTE: C/C_o applies only to capacitance, even if Q/t is selected. Also, sending a C command during current will give a "conflict error".

4.9.16 Capacitance Modifiers (Q)

Purpose Use with the instrument in the capacitance function (F0) to display the capacitance reading or the Q/t current reading. Also use to automatically correct the capacitance readings for leakage current.

Format **Qn**

Parameters
n = 0 Capacitance displayed, capacitance not corrected
n = 1 Q/t displayed, capacitance not corrected
n = 2 Capacitance displayed, capacitance corrected
n = 3 Q/t displayed, capacitance corrected

Description **Display**—With the instrument in the capacitance function (F0), capacitance readings will be displayed when Q0 or Q2 is sent over the bus. When Q1 or Q3 is sent, Q/t current readings will be displayed.

Correction—When the voltage step occurs, the device under test will change to its new equilibrium state. Once equilibrium has been reached, only DC leakage currents will flow. Q/t represents the current measured during the last $^1/_8$ of the delay time (or 44msec, whichever is greater). The Q2 and Q3 commands are used to correct the capacitance reading for DC leakage current errors.

Default Upon power up or after a DCL or SDC command is received, the instrument will be in Q0.

Reference Equivalent front panel control of the display (capacitance or Q/t) is accomplished with SHIFT then CAPACITANCE (Q/T) (see paragraph 3.3.2). Correction is accomplished through a front panel program (see paragraph 3.4.6).

Example Place the instrument in the capacitance function and enter the following statements into the computer to display the uncorrected Q/t value (Q1):

```
REMOTE 728
OUTPUT 728;''Q1X''
OUTPUT 728; ''Q0X''
```

When END LINE is pressed the second time, the Q/t value will be displayed. After END LINE is pressed the third time, the unit will return to uncorrected capacitance display.

NOTES:

1. Using capacitance correction with a non-equilibrium measurement will yield incorrect results. See paragraph 3.4.6 for details.
2. Sending the Q command while the instrument is in the current function (F1) will result in a conflict error (see paragraph 4.7.3).
3. The C and N commands apply only to the capacitance reading, even while displaying Q/t.

4.9.17 Prefixes (G)

Purpose Controls the format of the data string sent by the instrument.

Format **Gn**

Parameters

TERMINATE ON EACH READING
G0 n = 0 Reading; prefix
G1 n = 1 Reading; no prefix
G2 n = 2 Plotter; prefix
G3 n = 3 Plotter; no prefix

TERMINATE ON EACH NON-STAIRCASE READING
G4 n = 4 Reading; prefix
G5 n = 5 Reading; no prefix
G6 n = 6 Plotter; prefix
G7 n = 7 Plotter; no prefix

Description

Normal format—The prefix identifies the reading that is sent over the bus. Figures 4-6A and B show the format of these readings. The various prefixes shown are only sent when the instrument is in G0, G2, G4 or G6. When G1, G3, G5 or G7 are sent, the prefix is not included with the reading (i.e., +1.23456E−12, −001.50).

Plotter format—This format lists the data plot points (voltage vs. reading) that can be sent to an IEEE plotter when using IEEE-Plot. The data for the reading corresponds to the A/D output (counts) and does not reflect the range that the instrument is on. For example, 236pF applied to the input will show a plotter format reading of 2360 on the 2nF range and 236 on the 20nF range. The plotter format is shown in Figure 4-6C.

Commands G4-G7 provide a way to send a continuous string during fast staircase measurement in a slow controller situation. The readings are separated by commas. A terminator (see Y and K commands) will be sent with the first and all subsequent readings after the staircase.

Default Upon power up or after a DCL or SDC command is received, the instrument will be in G0.

Example Enter the following statements into the computer to send a reading without the prefix over the bus:

```
REMOTE 728
OUTPUT 728;"G1X"
ENTER 728;A$
DISP A$
```

After END LINE is pressed the second time, the instrument will be in G1. After END LINE is pressed the third time, the instrument will be addressed to talk and will send a reading over the bus. After END LINE is pressed the fourth time, the reading, without the prefix, will be displayed on the computer CRT.

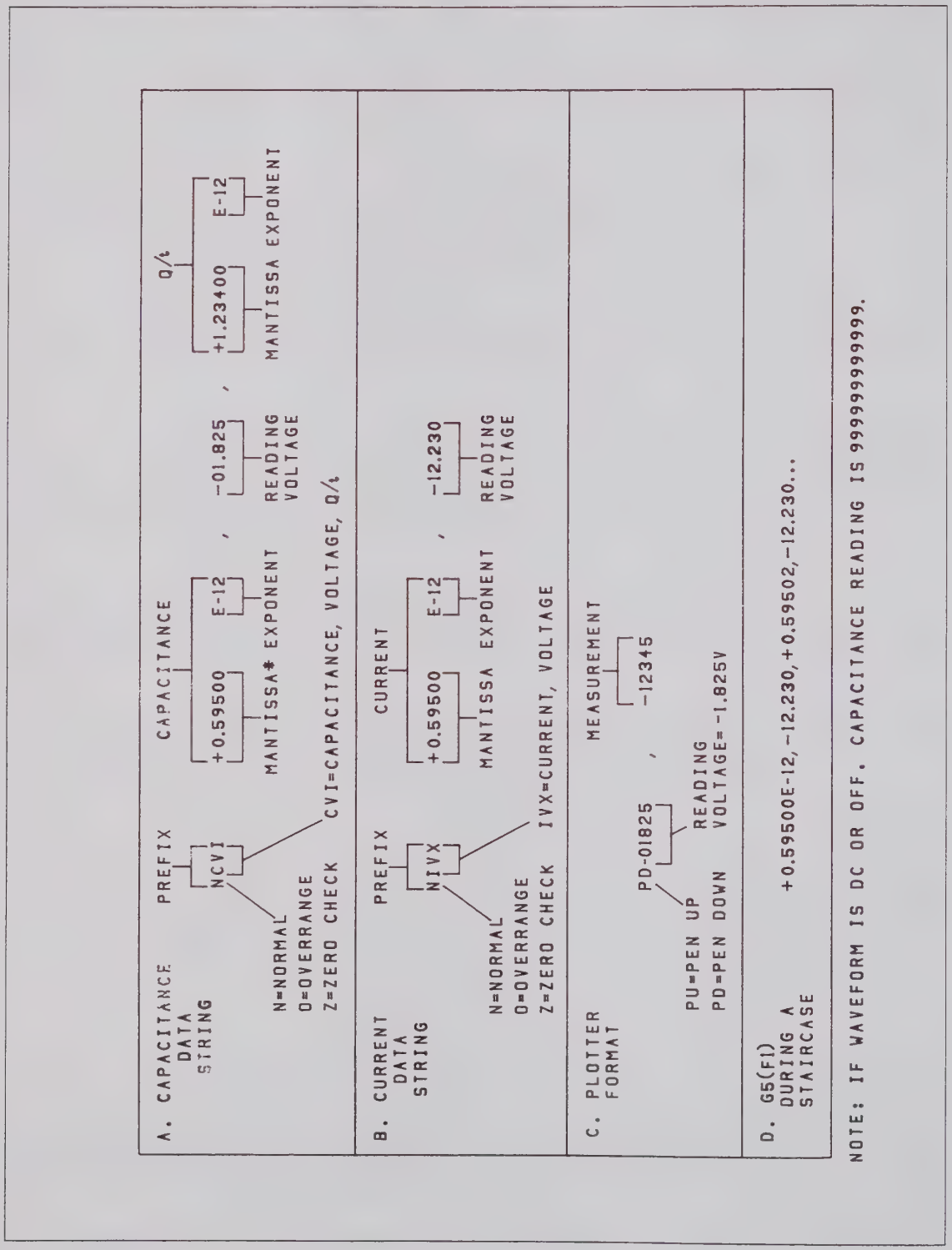


Figure 4-6. General Data Format

4.9.18 Analog Output (O)

Purpose

Use to control the sensitivity of the analog output and the pen of an analog X-Y recorder.

Format

On

Parameters

n = 0 Autopen, X1 Gain
n = 1 Pen Up, X1 Gain
n = 2 Pen Down, X1 Gain
n = 3 Same as 1
n = 4 Autopen, X10 Gain
n = 5 Pen Up, X10 Gain
n = 6 Pen Down, X10 Gain
n = 7 Same as 4

Description

Pen Control—The purpose of pen control is to keep the pen off the paper when not plotting. In Autopen (O0, O4), the pen automatically comes down at the beginning of a staircase sweep and automatically goes up at the end of the staircase and remains up for all non-staircase waveforms. The O2 and O6 commands can be used to force the pen down, while O1 and O5 will force the pen up.

Gain Control—The O command also controls the gain of the C,I, (Q/t) ANALOG OUTPUT. At X1 gain, 10,000 display counts will output 1V. At X10 gain, 1000 display counts will output 1V. Regardless of the gain, maximum analog output is ±2V.

Default

Upon power up or after a DCL or SDC command is received, the instrument will be in O0.

Reference

From the front panel, the analog output is controlled by a front panel program. See paragraph 3.4.5 for complete information on the analog output program.

Example

Enter the following program statements into the computer to place the analog output in Pen Up, X1 (O1):

```
REMOTE 728
OUTPUT 728;"O1X"
OUTPUT 728;"O2X"
```

When END LINE is pressed the second time the analog output will be set to O1. When END LINE is pressed the third time, the analog output will be set to O2, Pen Down.

4.9.19 Trigger Mode (T)

Purpose The trigger mode defines the conditions which will trigger a reading.

Format **Tn**

Parameters
n = 0 Continuous on Talk
n = 1 One-shot on Talk
n = 2 Continuous on GET
n = 3 One-shot on GET
n = 4 Continuous on X
n = 5 One-shot on X
n = 6 Continuous on External Trigger
n = 7 One-shot on External Trigger

Description When set to continuous trigger, a single trigger command is used to start a continuous series of readings. In a one-shot trigger, a separate trigger stimulus is required to start each conversion (reading).

Triggers are paired according to the type of stimulus that is used to trigger the instrument. Talk is when the Model 595 is addressed to talk. GET is the IEEE-488 Group Execute Trigger. "X" is the Keithley execute command. External trigger is the rear panel BNC connection (a falling edge TTL level is required).

Note that when a trigger command (Tn) is sent, the instrument will stop making measurements and display the "triG" message. Measurements will continue when the required trigger occurs. When set for a staircase output, the voltage source output will switch to DC and display the "triG" message when a trigger command is sent. To continue the staircase, first set the voltage source to output the staircase (W3) and then apply the required trigger.

Default Upon power up or after the instrument receives a DCL or SDC command, the Model 595 will return to T6 and supply its own trigger to start.

Example From the front panel, set up the parameters for a staircase capacitance measurement, leaving the Model 595's waveform at DC. Enter the following statements into the computer to demonstrate a one-shot trigger:

```
REMOTE 728
OUTPUT 728;''D0W3X''
OUTPUT 728;''T3X''
OUTPUT 728;''W3X''
TRIGGER 728
```

When the END LINE key is pressed the second time, the staircase will start and capacitance readings will be displayed. When END LINE is pressed the third time, the instrument will be placed in the one-shot on GET trigger mode, the voltage source switches to a DC output (staircase stops) and the "triG" message is displayed. When END LINE is pressed the fourth time, the voltage source is set to output a staircase. When END LINE is pressed the last time one reading will be triggered and displayed. For another example, substitute D1 for D0 and later T2 for T3.

4.9.20 SRQ Mask (M) and Serial Poll Byte Format

Purpose

The M command selects which condition(s) will cause the the instrument to assert the SRQ (Service Request) line to the bus controller.

Format

Mn

Parameters

n = 0 Clear SRQ mask
n = 1 Reading overflow
n = 2 Not used
n = 4 Staircase done
n = 8 Reading done
n = 16 Ready
n = 32 Error

Description

SRQ Mask—The Model 595 uses an internal mask to determine which conditions will cause an SRQ to be generated. Figure 4-7 shows the general format of this mask, which is made up of eight bits. The SRQ mask has the same general format as the serial poll byte (described below) except for the fact that bits 6 and 7 are not used in the SRQ mask.

The Model 595 can be programmed to generate an SRQ under one or more of the following conditions:

1. If a reading overflow occurs (M1).
2. When a staircase sweep is complete (M4).
3. When a reading is done (M8).
4. When the instrument is ready to accept bus commands (M16).
5. When an error condition occurs (M32)

Note that the instrument may be programmed for more than one set of conditions simultaneously. To do this, simply add up the decimal bit values for the required SRQ conditions. For example, to enable SRQ under reading overflow and staircase done conditions, send M5X. To disable SRQ, send M0X.

Once an SRQ is generated, the serial poll byte can be checked to determine if the Model 595 was the instrument that asserted SRQ.

Serial Poll Byte Format—The serial poll byte contains information relating to data and error conditions within the instrument. The general format of this status byte (which is obtained by using the serial polling sequence, as described in paragraph 4.8.8) is shown in Figure 4-7. Note that the various bits correspond to the bits in the SRQ mask as described above.

The status bits in the serial poll byte have the following meanings:

Bit 0 (Reading Overflow)—Set when an overranged input is measured. Cleared when an on-range input is measured.

Bit 1—Not used; always set to zero.

Bit 2 (Non-staircase Reading)—Set whenever a non-staircase reading is taken. Cleared when a staircase is in process. Used to indicate the end of a staircase.

Bit 3 (Reading Done)—Set when the instrument has a reading available. Cleared by sending the reading to the controller.

Bit 4 (Ready)—Set when the instrument has processed all previously received commands and is ready to accept additional commands over the bus. Cleared upon receipt of "X". Use when hold off on "X" is disabled (K2, K3).

Bit 5 (Error)—Set when one of the following errors have occurred:

1. An illegal device dependent command (IDDC) or an illegal device dependent command option (IDDCO) was transmitted.
2. The instrument was programmed when not in remote.
3. A conflict error has occurred (sending a Q or C command while in the current function).
4. A trigger overrun has occured (the instrument was triggered while processing a reading from a previous trigger).
5. A number error has occured (invalid calibration value or voltage source value sent over the bus).

Bit 5 remains set until the U1 status is read to determine the type of error (see 4.9.23).

Bit 6 (RQS=Request for Service)—Set if the Model 595 asserted SRQ. Cleared when the instrument is serial polled.

Bit 7—Not used; always set to zero.

Note that the status byte should read to clear the SRQ line once the instrument has generated an SRQ. The SRQ line is asserted on the false-to-true transition of a status bit if the corresponding mask bit is set. All bits in the status byte will be latched when the SRQ is generated.

Default Upon power up or after a DCL or SDC command is received, SRQ is disabled (M0).

Example

Enter the following program to generate an SRQ on an IDDC bus error:

PROGRAM	COMMENTS
`10 REMOTE 728`	Send remote enable.
`20 CLEAR 728`	Clear 595 (SDC).
`30 OUTPUT 728;''M32X''`	Program for SRQ on error.
`40 OUTPUT 728;''E2X''`	Attempt to program illegal command.
`50 S=SPOLL(728)`	Serial poll the instrument.
`60 DISP ''B7 B6 B5 B4 B3 B2 B1 B0''`	Identify the bits.
`70 FOR I=7 TO 0 STEP -1`	Loop eight times.
`80 DISP BIT(S,I);`	Display each bit position.
`90 NEXT I`	
`100 DISP`	
`110 END`	

Once the program is entered and checked for errors, press the HP-85 RUN key. Line 20 sets the instrument to the power-up default conditions. Line 30 programs the SRQ mode. Line 40 then attempts to program an illegal command, at which point the instrument generates an SRQ and sets the bus error bit in its serial poll byte. The computer then serial polls the instrument (line 50), and then displays the status byte bits in proper order on the CRT. In this example, the SRQ (B6) and error (B5) bits are set because of the attempt to program an illegal command (E2). Other bits may also be set depending on instrument status.

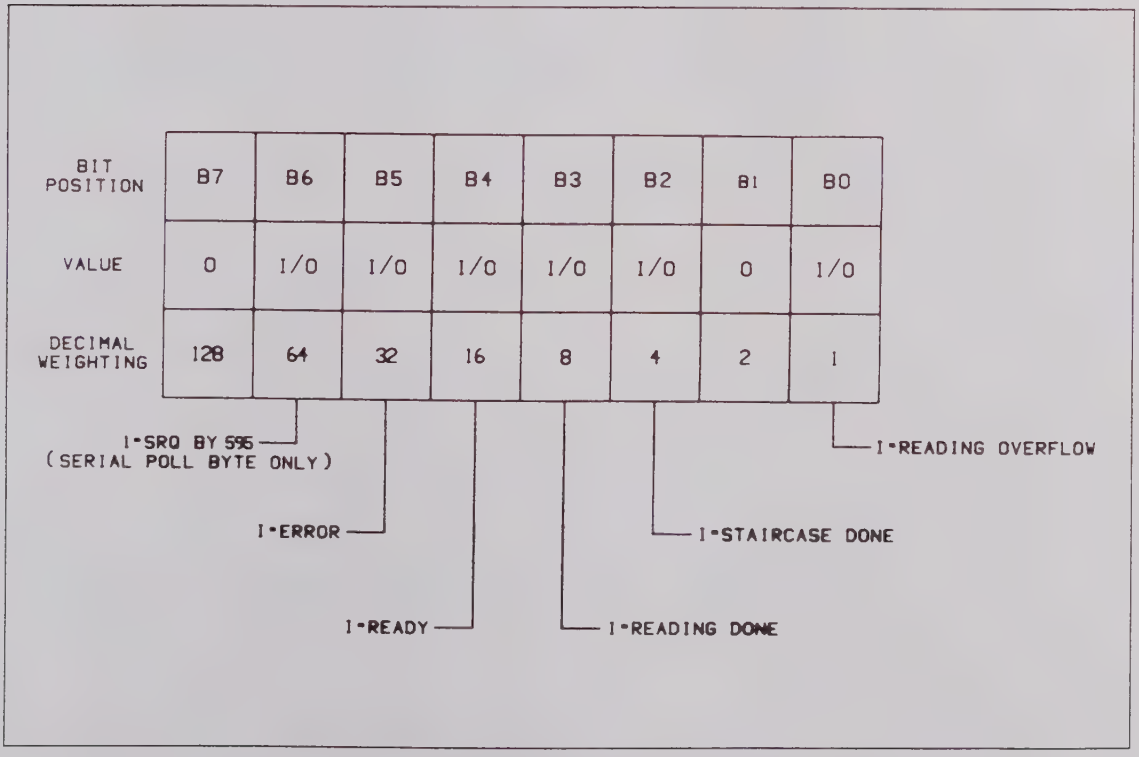


Figure 4-7. SRQ Mask and Serial Poll Byte Format

4.9.21 EOI and Bus Hold-off Modes (K)

Purpose

Provides control over whether or not the instrument sends the EOI status at the end of its data string, and whether or not bus activity is held off (through the NRFD line) until all commands sent to the instrument are internally processed once the instrument receives the X character.

Format

Kn

Parameters

n = 0 Send EOI with last byte of reading; hold off bus until commands processed on X.

n = 1 Do not send EOI with last byte of reading; hold off bus until commands processed on X.

n = 2 Send EOI with last byte of reading; do not hold off on X.

n = 3 Do not send EOI with last byte of reading; do not hold off on X.

Description

The EOI line on the IEEE-488 bus provides a method to positively identify the last byte in a multi-byte transfer sequence. Keep in mind that some controllers rely on EOI to terminate their input sequences. In this case, suppressing EOI with the K command may cause the controller input sequence to hang unless other terminator sequences are used.

Bus hold off allows the instrument to temporarily hold up bus operation when it receives the X character until it processes all commands sent in the command string. The purpose of the hold off is to ensure that the front end FETs and relays are properly configured before taking a reading. Keep in mind that all bus operation will cease for the hold off duration—not just activity associated with the Model 595. The advantage of this is that no bus commands will be missed while the instrument is processing commands previously received. Use the ready bit of the serial poll byte (see paragraph 4.9.20) when not holding off on X.

The hold off period depends on the commands being processed. Table 4-7 lists hold-off times for a number of different commands.

Table 4-7. Bus Hold-Off Times

Command	X Hold Off/Busy Until
J19	Permanent storage completed (13msec)
F, R, Z	Model 595 front panel is set up (20msec)
A	Calculate calibration constant (5msec)
ELSE	As soon as "X" is recognized (2msec)

NOTE: RFD will be held off until each byte in is recognized (2-60msec in continuous, 2msec is single shot); only exceeds 2msec for one character while reading is calculated.

Default

Upon power up, or after the instrument receives a DCL or SDC command, the instrument will return to K0.

Example

To program the instrument for K2, enter the following statements into the HP-85:

```
REMOTE 728
OUTPUT 728;''K2X''
```

When the second statement is executed, the instrument will be placed in K2. EOI will be transmitted at the end of the reading data string, without bus hold off on X.

4.9.22 Terminator (Y)

Purpose Use to select the ASCII terminator sequence that marks the end of the instrument's data string or status word.

Format **Yn**

Parameters
n = 0 CR LF
n = 1 LF CR
n = 2 CR
n = 3 LF
n = 4 No terminator

Description A terminator sequence can be programmed by sending the Y command followed by an appropriate parameter. One of the most commonly used terminators is the carriage return, line feed (CR LF) sequence (Y0). Selecting the wrong terminator for the controller could cause the bus to hang up.

Default Upon power up or after a DCL or SDC command is received, the Y0 terminator will be selected.

Example To select the line feed, carriage return (LF CR) terminator sequence, type the following lines into the computer:

```
REMOTE 728
OUTPUT 728;"Y1X"
```

When the second statement is executed, the LF CR terminator sequence will be used; the instrument will terminate each data string or status word with an LF CR sequence. This may cause problems in controllers which terminate on LF and don't discard CR.

4.9.23 Status (U)

Purpose Use to access information concerning various operating conditions of the Model 595.

Format **Un**

Parameters
n = 0 Send Machine Status Word
n = 1 Send Error Status Word
n = 2 Send Data Status Word
n = 3 Send Delay Time
n = 4 Send High and Low Limits of Voltage Source
n = 5 Send Voltage Source Setting

Description When the command sequence UnX is transmitted, the instrument will transmit the appropriate status word instead of its normal data string when it is addressed to talk. The status word will be transmitted only once for each Un command.

U0: The format of U0 status is shown in Figure 4-8. Note that the letters correspond to modes programmed by the respective device-dependent commands. The default values in the status word are also shown in Figure 4-8.

Note that all returned values correspond to the programmed numeric values.

U1: The U1 command allows access to Model 595 error conditions. The error status word (Figure 4-9) is actually a string of ASCII characters representing binary bit positions. Reading the U1 status clears the error bits. An error condition is also flagged in the serial poll byte, and the instrument can be programmed to generate an SRQ when an error condition occurs (see paragraph 4.9.20).

The various bits in the U1 Error Status words are described as follows:

IDDC—Set when an illegal device-dependent command (IDDC) such as E1X is received ("E" is illegal). (bErr, bus error)

IDDCO—Set when an illegal device-dependent command option (IDDCO) such as T9X is received ("9" is illegal). (bErr)

No Remote—Set when a programming command is received when REN is false. (bErr)

Conflict—Set when trying to send a Q or C command while the instrument is in the current function. (nErr)

Trigger Overrun—Set when the instrument receives a trigger while it is still processing a reading from a previous trigger (or continuous). (tErr)

Number—Set when an out of range calibration value (A) or voltage source value (V, H, L, I) is sent over the bus. (nErr, number error)

Self Test—Set when the self-test (J0) has failed.

5 9 5 F 0 R 3 Z 1 N 0 C 0 W 2 S 2 Q 0 P 0 T 6 G 0 D 0 O 0 M 0 0 K 0 Y 0

MODEL NUMBER PREFIX (595)

FUNCTION (F)
0 = CAPACITANCE
1 = CURRENT

RANGE (R)

	F0	F1
1 =	200pF	20pA
2 =	2nF	200pA
3 =	20nF	2nA
4 =		20nA
5 =		200nA
6 =		2 μA
7 =		20 μA
8 =		200 μA

ZERO CHECK (Z)
0 = OFF
1 = ON

SUPRESS (N)
0 = OFF
1 = ON

C/C_o (C)
0 = C/C_o OFF
1 = C/C_o ON

WAVEFORM (W)
0 = OFF
1 = DC
2 = SQUARE WAVE
3 = STAIRCASE

STEP VOLTAGE (S)
0 = 10mV
1 = 20mV
2 = 50mV
3 = 100mV
4 = −10mV
5 = −20mV
6 = −50mV
7 = −100mV

CAPACITANCE MODIFIERS (Q)
0 = CAP, DISPLAYED, CAPACITANCE NOT CORRECTED
1 = Q/t DISPLAYED, CAPACITANCE NOT CORRECTED
2 = CAP, DISPLAYED, CAPACITANCE CORRECTED
3 = Q/t, DISPLAYED, CAPACITANCE CORRECTED

FILTER (P)
0 = OFF
1 = FILTER 1
2 = FILTER 2
3 = FILTER 3 (DC)

TRIGGERS (T)
0 = CONTINUOUS ON TALK
1 = ONE-SHOT ON TALK
2 = CONTINUOUS ON GET
3 = ONE-SHOT ON GET
4 = CONTINUOUS ON X
5 = ONE-SHOT ON X
6 = CONTINUOUS ON EXTERNAL TRIGGER
7 = ONE-SHOT ON EXTERNAL TRIGGER

PREFIX (G)
TERMINATE ON EACH READING
0 = READING; PREFIX
1 = READING; NO PREFIX
2 = PLOTTER; PREFIX
3 = PLOTTER; NO PREFIX
TERMINATE ON EACH NON-STAIRCASE READING
4 = READING; PREFIX
5 = READING; NO PREFIX
6 = PLOTTER; PREFIX
7 = PLOTTER; NO PREFIX

DISPLAY (D)
0 = METER
1 = VOLTAGE SOURCE
2 = HIGH LIMIT
3 = LOW LIMIT
4 = STEP VOLTAGE
5 = DELAY TIME

ANALOG OUTPUT (O)
0 = AUTOPEN, X1 GAIN
1 = PEN UP, X1 GAIN
2 = PEN DOWN, X1 GAIN
3 = SAME AS 1
4 = AUTOPEN, X10 GAIN
5 = PEN UP, X10 GAIN
6 = PEN DOWN, X10 GAIN
7 = SAME AS 4

SRQ MASK (M)
00 = MASK CLEARED
01 = READING OVERFLOWED
02 = NOT USED
04 = STAIRCASE DONE
08 = READING DONE
16 = READY
32 = ERROR

EOI (K)
0 = EOI and HOLD OFF ON X
1 = NO EOI AND HOLD OFF
2 = EOI AND NO HOLD OFF
3 = NO EOI AND NO HOLD OFF

TERMINATOR (Y)
0 = CR LF
1 = LF CR
2 = CR
3 = LF
4 = NONE

Figure 4-8. U0 Machine Status Word (Default Conditions Shown)

MODEL NO. (PREFIX)	IDDC	IDDCO	NO REMOTE	CONFLICT	TRIGGER OVERRUN	NUMBER	SELF-TEST		
595	1/0	1/0	1/0	1/0	1/0	1/0	1/0	0 0	<TERM>

Figure 4-9. U1 Error Status Word

NOTES:

1. The complete command string will be ignored if an IDDC, IDDCO or no remote (bErr) error occurs.
2. Within a command string, only the command(s) causing an "nErr" will be ignored.
3. Reading the U1 Error Status Word will reset the error bits.
4. Front panel messages identifying bus errors are explained in paragraph 4.7.1.

U2: The U2X sequence allows access to instrument data conditions. The U2 word is made up of ASCII characters representing binary values (0 or 1). The bits in the U2 data status word are described as follows:

MODEL NO.	TEMPORARY CAL	VOLTAGE SOURCE I-LIMIT	STORAGE ENABLED	50Hz		
595	1/0	1/0	1/0	1/0	0 0 0 0 0	<TERM>

Figure 4-10. U2 Data Status Word

Temporary Cal—Set when a calibration constant is altered and not stored in permanent memory, or if there was a permanent memory data error.

Voltage Source Overload—Set when the current limit (2-4mA) of the voltage source has been reached.

Cal Storage Enabled—Set when storage of calibration constants is enabled.

50Hz—Set to indicate instrument line frequency setting.

U3: The U3 command allows access to the delay time setting. The time units are in seconds.

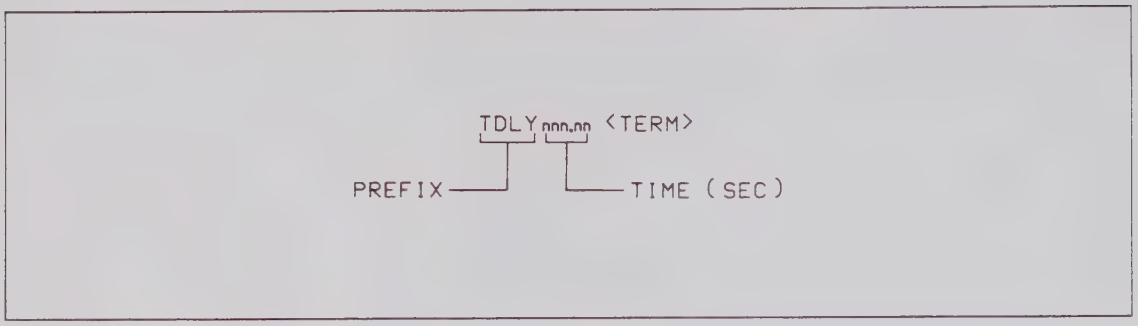


Figure 4-11. U3 Delay Time

U4: The U4 command allows access to the high and low limit settings of the voltage source.

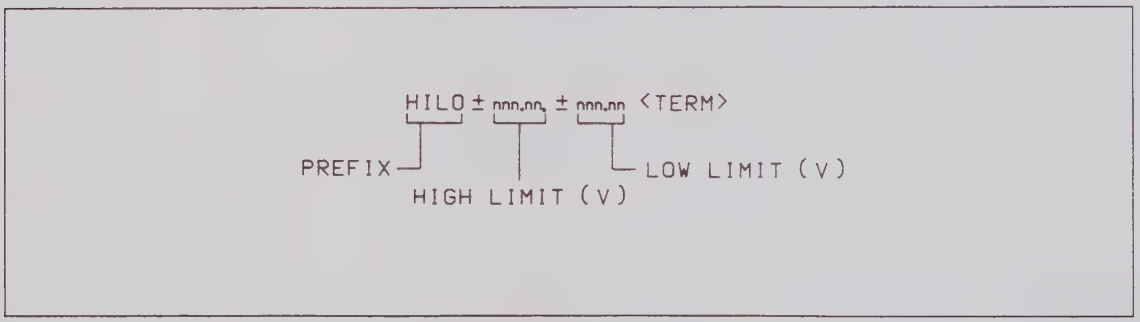


Figure 4-12. U4 Voltage Source Limits

U5: The U5 command allows access to the voltage source programmed value.

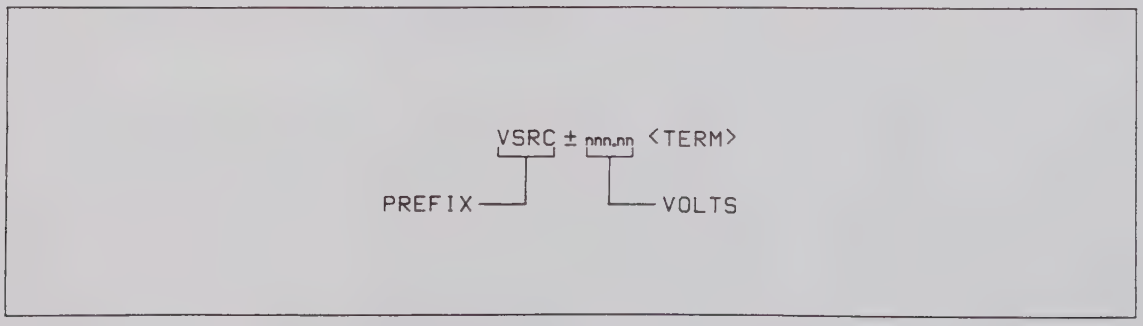


Figure 4-13. U5 Voltage Source Bias Settings

Default

Upon power up or after a DCL or SDC command is received, the machine status (U0) will default to the values shown in Figure 4-8, the bits in the error status word (U1) will clear (0), the time delay (U3) will reset to 0.07 seconds, the limits (U4) will reset to ±20V, and the voltage source (U5) will reset to 0V.

Example

Enter the following statements into the computer to obtain and display the U0 machine status word of the Model 595:

PROGRAM	COMMENTS
`10 REMOTE 728`	Send remote enable.
`20 DIM A$[50]`	
`30 OUTPUT 728;"U0X"`	Send U0 command.
`40 ENTER 728;A$`	Obtain U0 status from instrument.
`50 DISP A$`	Display U0 status word.
`60 END`	

After entering the program, run it by pressing the HP-85 RUN key. Line 30 will send the U0 command, and then the U0 status word will be obtained and displayed on the CRT of the computer (lines 40 and 50). Also try U1 through U5.

4.9.24 Digital Calibration (A)

Purpose Use to send calibration values over the bus.

Format **Annn.nnE−nn**

Parameters nnn.nnE−nn = On-range calibration value using exponent.

NOTE: Only as many significant digits as necessary need be sent (i.e., send 1.9E−9 instead of 001.90E−09).

Description In general, calibration of the Model 595 over the IEEE-488 bus consists of applying a precise calibration signal to the Model 595 input and sending the corresponding calibration value over the bus using the A command.

CAUTION

Precision calibration signals must be connected to the instrument before attempting calibration, otherwise instrument accuracy will be affected.

Reference Section 7, Maintenance, provides complete details on calibrating the instrument from either the front panel or over the bus.

Example A sample program to calibrate the instrument over the bus can be found in Section 7 of this manual.

4.9.25 Self-Test and Permanent Memory Storage (J)

Purpose

The J command is used by the Model 595 to perform tests on its memory elements and to permanently store calibration constants.

Format

Jn

Parameters

n = 0 Perform self-test
n = 19 Store calibration constants in permanent memory

Description

Self-test—When the J0 command is sent over the bus, the instrument performs the following tests on its memory elements:

1. ROM test
2. RAM test

If the self-test is successful, the self-test error bit in the U1 status word will be set to 0. Otherwise this bit will be set to 1. The test does not affect any data within the memory.

Permanent Storage—When the J19 command is sent, calibration constants are stored in permanent memory if the calibration jumper is configured to "store".

Reference

The instrument performs a number of self-tests on power-up. Calibration and subsequent storage of calibration constants are explained in Section 7.

Enter the following statements into the computer to perform the self-test:

```
REMOTE 728
OUTPUT 728;''J0X''
```

When the END LINE key is pressed the second time, the instrument performs the self-test. If successful, the self-test error bit in the U1 status word will be set to 0.

4.10 PROGRAMMING EXAMPLES

The following programs demonstrate how to make capacitance and current measurements over the bus using the HP-85 computer as a controller.

4.10.1 Square Wave Capacitance Measurements

Enter the following statements into the computer to make square wave capacitance measurements:

PROGRAM	COMMENTS
`10 REMOTE 728`	Send remote enable.
`20 DIM A$[40]`	
`30 CLEAR 728`	
`40 OUTPUT 728;"W0X"`	Set voltage source off.
`50 OUTPUT 728;"U5S3I .5X W2X"`	Defines measurement parameters.
`60 OUTPUT 728;"Z0X"`	Release zero check.
`70 ENTER 728;A$`	Receive reading over bus.
`80 DISP A$`	Display reading on computer.
`90 GOTO 70`	Repeats cycle of readings.
`100 END`	

Press the RUN key to run the program. Line 30 will place the instrument in the capacitance function with zero check enabled (default conditions). Line 40 will turn the voltage source off. Line 50 will set the voltage source for 5V in square wave, step voltage for 100mV and delay time for 0.5 seconds. Line 60 releases zero check. Lines 70 and 80 receive and display a capacitance reading on the computer. Line 90 repeats the cycle.

4.10.2 Staircase Measurements

Enter the following statements into the computer to make staircase measurements:

PROGRAM	COMMENTS
`10 REMOTE 728`	Place 595 in remote.
`20 DIM A$[40]`	
`30 CLEAR 728`	Set 595 to default conditions.
`40 OUTPUT 728;"W0X"`	Turn voltage source off.
`50 OUTPUT 728; "U-2XS3I1H2X"`	Define measurement parameters.
`60 OUTPUT 728;"W1X"`	Set voltage source for DC output.
`70 WAIT 2000`	Let device under test settle at −2V for 2sec.
`80 OUTPUT 728;"Z0XW3X"`	Disable zero check and set voltage source for staircase output.
`90 S=SPOLL(728)`	Serial poll 595 until staircase starts.
`100 IF BIT(S,2)=1 THEN 90`	
`110 S=SPOLL(728)`	Serial poll 595 for end of staircase.
`120 IF BIT(S,2)=1 THEN 160`	
`130 ENTER 728;A$`	Send reading to computer.
`140 DISP A$`	Display reading on CRT of computer.
`150 GOTO 110`	Loop back to line 110.
`160 END`	

*To measure current, add F1 to the command string in line 50.

Press the RUN key to run the program. Line 40 will turn the voltage source off. Line 50 will set the bias voltage to 0V, step voltage to 100mV, delay time to one second and the high limit to 2V. Line 60 will set voltage source for a DC output. Line 70 allows a couple of seconds for the device under test to settle. Line 80 will disable zero check and set the output for a staircase output. Lines 90 and 100 will serial poll the instrument until the staircase starts. Lines 110 through 150 will send and display each capacitance measurement and stop at the end of the staircase.

NOTES:

1. Make sure unit is not set to staircase when sending the V command, since the voltage source will go to "DC" at a step above the voltage values.
2. When terminating a staircase measurement, the voltage out will go to the next voltage source step.

4.10.3 Current Measurements

Enter the following statements into the computer to make current measurements:

NOTE: The following example program does not use the internal voltage supply; thus the current to be measured would be applied to the C, I METER INPUT connector. If no current source is available, connect a resistor between V_{out} and meter INPUT. Then set V_{out} for the desired current. (Use W1 instead of W0 in line 40).

PROGRAM	COMMENTS
10 REMOTE 728	Place 595 in remote.
20 DIM A$[40]	
30 CLEAR 728	
40 OUTPUT 728;''W0F1R8X''	Define measurement parameters.
50 OUTPUT 728;''Z0X''	Release zero check.
60 ENTER 728;A$	Send current reading over bus.
70 DISP A$	Display reading on CRT.
80 GOTO 60	
90 END	

Press the RUN key to start the program. Line 40 will turn off the voltage, select the current function and the 200μA range. Line 50 will release the zero check, and lines 60 and 70 will send and display the current reading on the computer CRT.

4.11 TALK ONLY

In Talk Only, the instrument will control the bus and output data to listening device. No controller may be on bus. The listening device may be a listen-only printer or an addressable printer whose address is set to 3. When the instrument is in Talk Only, the front panel TALK indicator light will turn on.

To place the instrument in Talk Only, perform the following steps:

1. Using the front panel PROGRAM MENU button, display the present IEEE-488 address value.
2. Using the voltage source ADJUST buttons, select one of the following Talk Only parameters:
   A. 40 Talk Only with prefix on data string (i.e. NCVI+1.23456E−12,−01.820, +1.23400E−12).
   B. 41 Talk Only without prefix on data string (i.e. +1.23456E−12,−01.820, +1.23400E−12).
3. Press the SHIFT button and then the program EXIT button. The instrument will start talking when the measurement sequence is started.
4. Change the IEEE-488 address or go to one-shot to stop talking.

NOTES:

1. When using Talk Only, there should not be a controller other than the Model 595 connected to the bus. Multiple Model 590s and 595s are permitted on the bus as long as only one instrument is talking at a time.
2. When in Talk Only or IEEE-Plot (see paragraph 4.12), two listening devices (printer and plotter) may be connected to the bus at the same time as long as they are in the addressable mode and set to the correct address (address 3 for the printer, address 5 for the plotter).
3. Using the printer will set the K, Y, and G modes (see Appendix H).

4.12 IEEE-PLOT

In IEEE-Plot, the instrument will output voltage and capacitance, Q/t or current data to an IEEE-488 plotter for the purpose of plotting the CV, IV, or Q/t-V curves of staircase measurements.

A grid can also be drawn with the labels corresponding to the selected function, range, voltage source limit, and Y HI, Y Lo values of the Model 595.

To use IEEE-Plot, connect an IEEE plotter to the bus connector of the Model 595 (set plotter address to 5 before power up) and perform the following steps:

1. From the front panel, set up the Model 595 to make staircase measurements (capacitance or current). First complete the configuration of the voltage source and meter block for the measurement. Do not start the staircase at this time.
2. Use the program MENU button to display the present IEEE address of the instrument.
3. Using the voltage source ADJUST buttons, set the address to 42 or to 43 (to reverse the direction of X axis). Install plotter pen #1.
4. Press the SHIFT button and then the program EXIT button.
5. Plot a grid for the subsequent measurement plot as follows:

A. Press the program MENU button until the following message is displayed:

Grid

B. To start the grid plot, press one of the voltage source ADJUST buttons. A grid will be plotted and labels will be placed on the X and Y axes. The labels on the X axis correspond to the programmed high and low voltage limits. The labels on the Y axis correspond to the Y HI and Y Lo program settings. "Y HI=2" corresponds to a full 20,000 count display, while "Y HI=.1" corresponds to a 100 count display. Adjust Y HI and Y Lo to "crop" the plot).

6. Press the SHIFT button, then program EXIT. The measurement plot will begin when the staircase is started.

NOTES:

1. The display can be toggled between capacitance and Q/t while plotting, without affecting the plot.
2. Changing functions, ranges, zero check or voltage source settings will cause the staircase and plot to stop. When the staircase is restarted, keep in mind that the labels on the plot correspond to the original function/range and voltage limits but the new plot parameters correspond to the new Model 595 settings.
3. When using IEEE-Plot, there should not be a controller other than the Model 595 connected to the bus. When multiple Model 595s or 590s are on the bus, only one can talk at a time.
4. When in IEEE-Plot or Talk Only (see paragraph 4.11), two listening devices (plotter and printer) may be connected to the bus at the same time as long as they are in the addressable mode and set to the correct address (address 5 for the plotter, address 3 for the printer).
5. Using the plotter sets the K, Y, and G modes. See Appendix H.

4.13 BUS DATA TRANSMISSION TIMES

A primary consideration is the length of time it takes to obtain a reading once the instrument is triggered to make a conversion. The length of time will vary somewhat depending on the selected function, trigger mode, and delay time. Table 4-8 gives typical times.

Table 4-8. Trigger to Reading Ready Times (in msec)

Function/Filter Level	Ranges							
	R1	R2	R3	R4	R5	R6	R7	R8
Capacitance/Filter 0	267	270	263					
Capacitance/Filter 1	265	265	265					
Capacitance/Filter 2	265	264	265					
Capacitance/Filter 3	265	265	263					
Current/Filter 0	139	138	138	144	139	143	155	145
Current/Filter 1	144	146	144	146	148	146	150	150
Current/Filter 2	144	145	138	139	138	140	138	145
Current/Filter 3	142	142	136	140	140	139	140	141

NOTE: This table corresponds to a configuration of a "trigger to first byte time" based on one-shot trigger by Talk and a delay time of 0.07sec.

SECTION 5
APPLICATIONS

5.1 INTRODUCTION

The Model 595 Quasistatic CV Meter facilitates the measurement of semiconductor device parameters, specifically, quasistatic capacitance and current. Using the built-in voltage source and an analog or digital plotter, plots of C or I versus V can be easily generated.

This section describes in detail some typical applications of the Model 595. Current and capacitance applications will be discussed separately. The current section will give information about measurement of high resistances and IV characteristics of various devices. The capacitance section will present guidelines for proper use of the function and valid interpretation of data for MOS device characterization. It will also compare the feedback charge method used by the Model 595 with two other techniques: the ramp method and the static or QV method. Lastly, a bibliography is provided on CV and related topics.

5.2 APPLICATIONS OF THE CURRENT FUNCTION

5.2.1 High Resistance Measurements

High impedance levels are frequently encountered in semiconductor devices and in fixtures used for device characterization. Some examples are MOS gate oxide, device to device isolation, probe-to-pedestal insulation material, and coaxial cable insulation. High resistances such as these can be measured using the Model 595 voltage source and the current function.

The measurement circuit used by the Model 595 is shown in Figure 5-1. The resistor is connected from the input of the Model 595 in the current function to the voltage source. Because the input of the Model 595 is a virtual ground, the voltage, V, applied to the resistor is equal to the voltage source output to within one millivolt. The current, I, flowing through the resistor is measured by the Model 595. The unknown resistance, R, is calculated from the sourced voltage and measured current using Ohm's law: R = V / I. For example, the highest resistance which can be measured in this manner is $10^{15}\Omega$. This would be done by setting the voltage source to 20V and measuring 0.020pA.

Since very high resistance measurements are subject to leakage current errors, circuit connections must be carefully made. To avoid unsuitably low leakage resistance, the device under test should be placed in a properly designed test fixture, such as the Keithley Model 6104 Test Box. The test box, when connected to the GUARD terminal of the Model 595, acts as an electrostatic shield, and to some extent an RFI shield, intercepting signals which would otherwise interfere with the input. It has the additional benefit of shielding the device from light, as many devices are photosensitive. The meter input of the Model 595 should be connected to the test fixture with low noise coaxial cable, such as the supplied Model 4801. The voltage source may be connected to the test box with ordinary banana plug test leads, using a BNC to banana plug adapter such as a Pomona Model 1296.

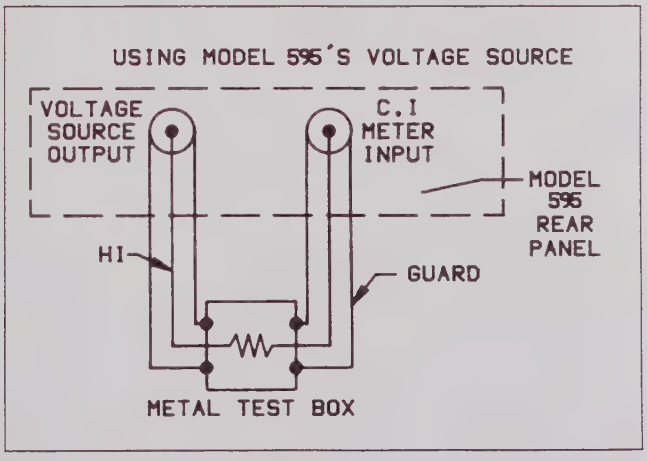


Figure 5-1. Current Measurement Corrections Using the Model 595 Voltage Source

5.2.2 Voltage Coefficients of High Resistances

High value resistances (above $10^9\Omega$) often exhibit substantial variation in resistance with applied voltage. This resistance variation is known as the voltage coefficient. The Model 595 is an ideal instrument for obtaining data to determine voltage coefficients because of its built-in variable voltage source and its highly sensitive current preamplifier.

Two resistance measurements at different voltages are required to calculate the voltage coefficient. The resistances are measured as described in Section 5.2.1. The voltage coefficient, VC, in %/V can then be calculated as follows:

$$VC\ (\%/V) = 100\ (R2 - R1) / R1\ (\Delta V)$$

where: R1 is the resistance with the first applied voltage
R2 is the resistance with the second applied voltage
ΔV is the difference between the two applied voltages

As an example, assume that the following values are obtained:

$R1 = 1.01 \times 10^{10}\Omega$
$R2 = 1.00 \times 10^{10}\Omega$
$\Delta V = 5V$

The resulting voltage coefficient is :

$$VC\ (\%/V) = 100\ (1 \times 10^{8}) / 10^{10}\ (5) = 0.2\ \%/V$$

Using the staircase waveform, a series of V,I data points may be generated to calculate the resistance value and voltage coefficient over a specific voltage range.

5.2.3 IV Characteristics of Diodes

The Model 595 can be used to measure IV characteristics of devices within the following ranges: current with 0.001pA resolution to 200μA maximum, and voltage with 0.01V resolution up to $\pm$20V. Within these constraints, the Model 595 can be used to characterize diodes, including zener diode references. An example curve of a 5.1V zener diode (1N751) is shown in Figure 5-2.

The same precautions should be taken to ensure that proper connections, cables and shields are used as described in Section 5.2.1. See Section 3.6 for information regarding setup, measurement and plotting of the IV data.

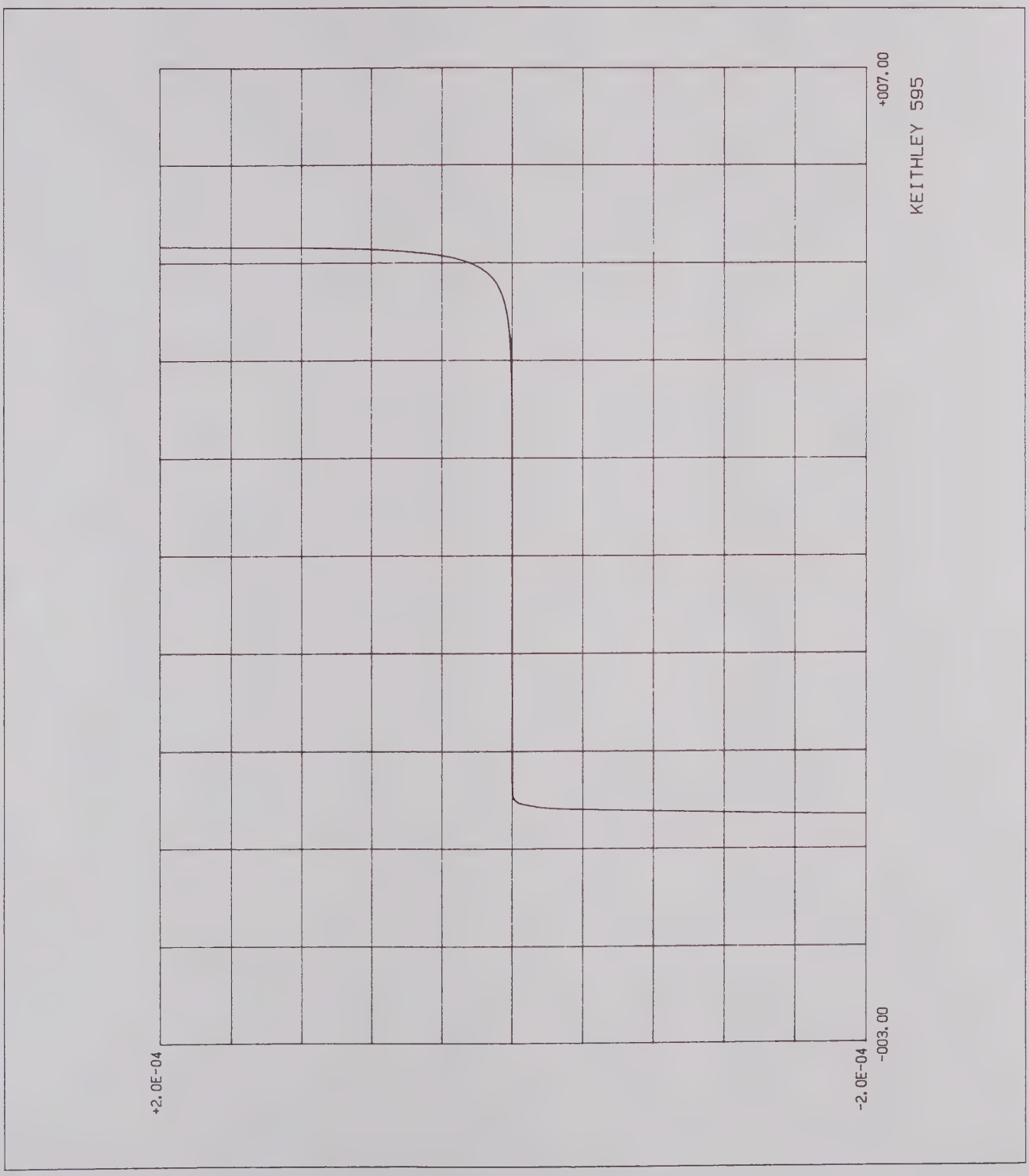


Figure 5-2. IV Characteristics of a Zener Diode (5.1V) 1N751

5.2.4 IV Characteristics of Transistors

Although the Model 595 is not a general purpose transistor tester, it can be useful in measurements requiring only low currents. Typical transistor IV measurements are those necessary to plot the common emitter characteristics of a bipolar transistor or the common source characteristics of a FET. Setups for each of these measurements are described in this section. The same principles apply to other semiconductor IV characteristic measurements.

Common Emitter Characteristics: Data for common emitter characteristics are generally obtained by setting the base current (I_B) to a known value and measuring the collector current (I_C) as the collector emitter voltage (V_{CE}) is varied. The circuit for this measurement is shown in Figure 5-3. This process is then repeated for a number of base current settings. Data may be plotted showing characteristics such as those in Figure 5-4.

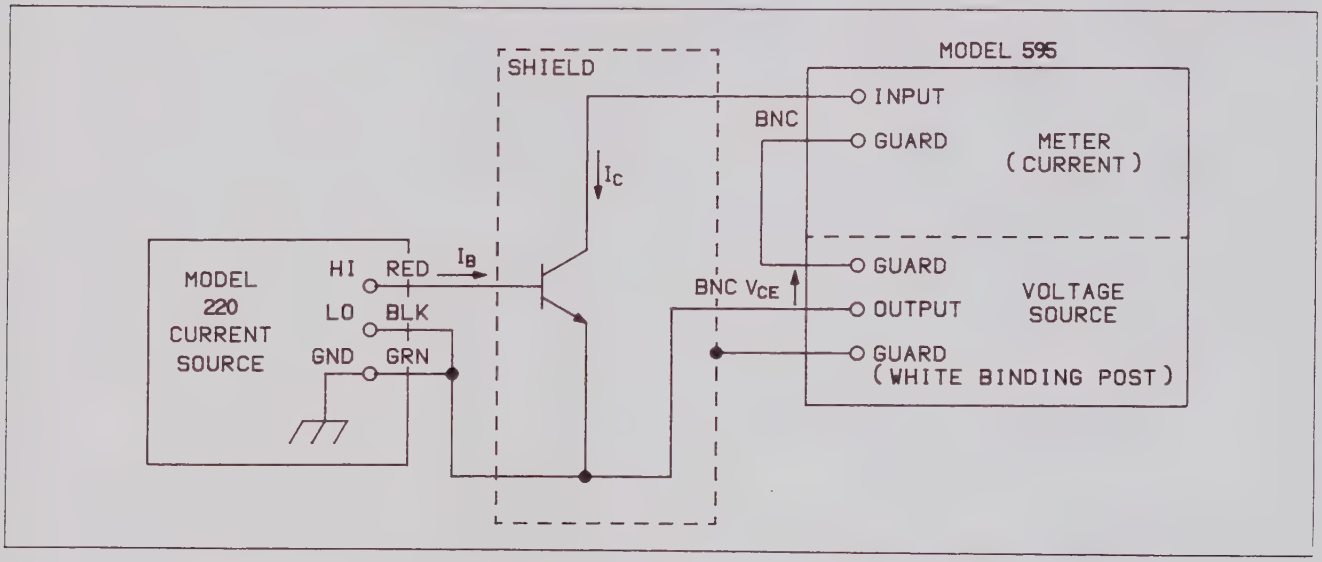


Figure 5-3. Connections for Bipolar Common-Emitter IV Characteristics

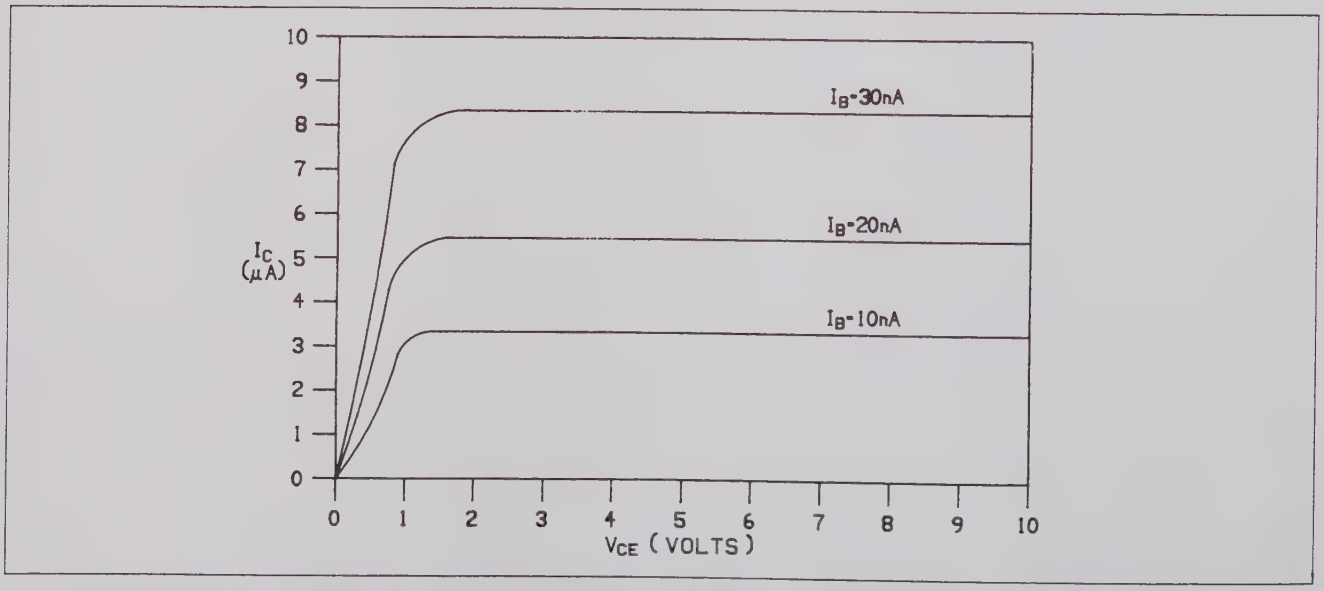


Figure 5-4. Typical Bipolar Common-Emitter Characteristics

In this example, a Keithley Model 220 Programmable Current Source is used to supply the base current, and the voltage source of the Model 595 is used to supply the collector emitter voltage. Measurement of collector current is made with the current function of the Model 595.

Note that the Model 220 OUTPUT COMMON and Model 595 GUARD terminals are connected to a low impedance point in the circuit, so that only the (very low) Model 595 input bias current disturbs the reading. If either of these terminals were tied to a high impedance point (such as the meter input), common-mode currents could also be injected into the circuit. The voltage source supplies minus V_{CE} to the emitter of the transitor.

Common Source Characteristics: The procedure for measuring the common source characteristics of a FET is very similar to the one just discussed. A setup to perform these measurements is shown in Figure 5-5.

Since a FET is voltage-controlled instead of current-controlled, the input signal to the gate (V_{GS}) is supplied by a Model 230 Programmable Voltage Source. The Model 595 supplies minus the drain-source voltage (V_{DS}) with its voltage source, and measures the drain current (I_D) in the current function. The procedure is to set V_{GS} to specific values and measure I_D as V_{DS} is varied. A graph of the data will be similar to the one shown in Figure 5-6.

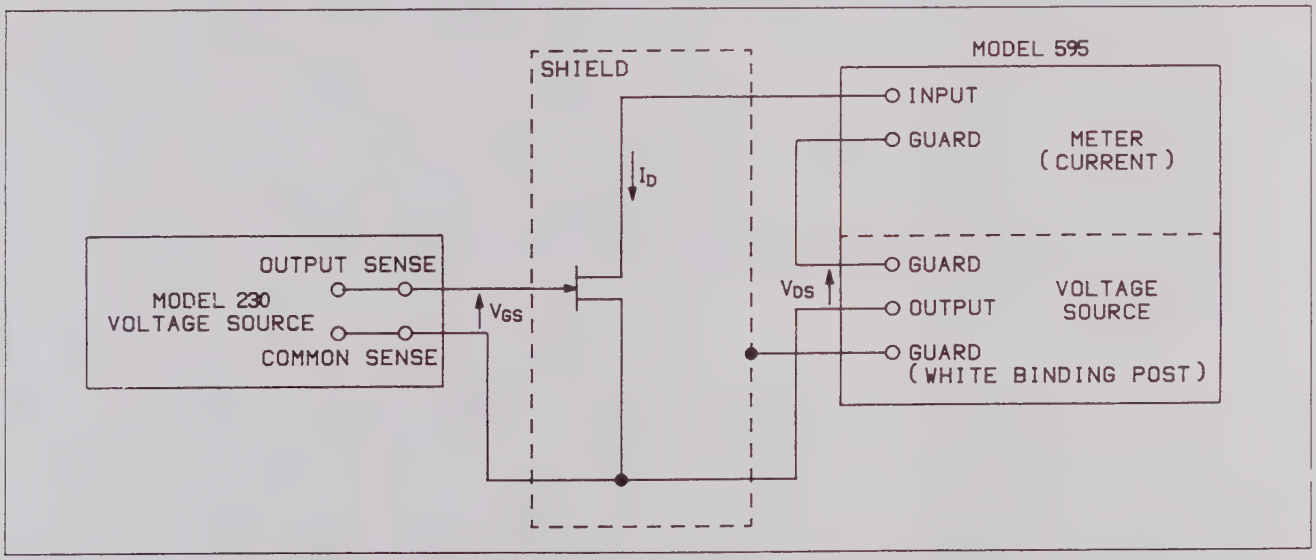


Figure 5-5. Connections for Common-Source FET IV Characteristics

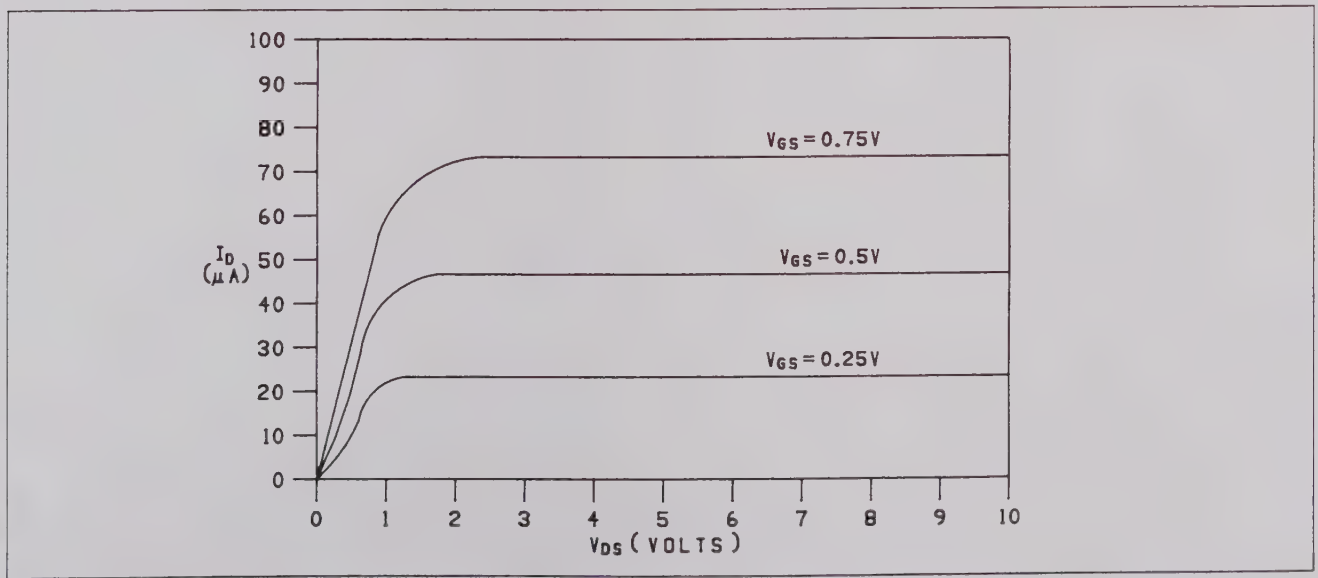


Figure 5-6. Typical Common-Source FET IV Characteristics

Note that the same grounding and shielding rules should be followed as in the previously described measurements. Also, by using the staircase waveform of the Model 595 and the digital plotter, curves can be easily generated. Note that to plot current versus V_{CE} or V_{DS}, IEEE-488 code 45 should be used to invert the voltage axis.

5.2.5 Low Level Leakage Current Measurements

Many devices exhibit low level leakage currents that may need to be characterized. Typically, such leakage currents lie in the nA (10^{-9}), pA (10^{-12}), or even fA (10^{-15}) range. The Model 595 is an ideal instrument for such current measurements because it can detect currents as low as 1fA.

An example of a low current measurement is a FET gate leakage determination, shown in Figure 5-7. Although the device manufacturer may specify the current value, it is often desirable to verify the specification for a particular sample of the device. In addition, the leakage current may be specified at a different voltage bias than required. For example, the specified leakage current might be 1nA with an applied voltage of 25V, while the application may only require 10V.

Advantages of the Model 595 in this measurement include its digital plotter drive and built-in voltage source, which can be used in the staircase waveform to automatically generate plots of leakage current versus gate voltage. Note that the delay time should be set long enough to allow the device and the Model 595 to settle at each new voltage. The Model 595 will settle within one reading in both capacitance and current except on the 2pA and 20pA ranges, which require 2.5sec to settle to 1%.

A second example of low current measurement is that of capacitor leakage. Once the leakage current is known, the insulation resistance can be calculated. Ideally, a capacitor should have no leakage current, and thus infinite leakage resistance. However, capacitors, like all practical devices, are not ideal, so these parameters can become important. The amount of leakage current in a given capacitor depends on its dielectric as well as the applied voltage. Ceramic dielectric capacitors typically have leakage currents in the nA to pA range while MOS or polystyrene dielectric devices exhibit much lower leakage currents--generally in the femtoamp range. (These values are for test voltages around 10V.)

The basic configuration for the capacitor leakage test is shown in Figure 5-8. The Model 595 voltage source is used to impress a voltage across the capacitor, C. The resulting leakage current is then measured by the Model 595 in the current function.

The resistor, R, is necessary to maintain stability and reduce noise when large capacitances are measured. Typically a value of about 1MΩ should be used. Refer to paragraph 3.13, Measurement Considerations, for more information.

At the start of the test, the Model 595 should be placed in the current function and on the 200μA range. The voltage source is then programmed to the desired voltage, and the waveform set to DC. Once a sufficient time has passed for the capacitor to fully charge, the instrument can be placed on the proper current range to make the measurement. The charging time is commonly referred to as the soak time. Typically, a soak time of 10(RC) is sufficient. Once the test is completed, the voltage source should be turned off to allow the capacitor to discharge.

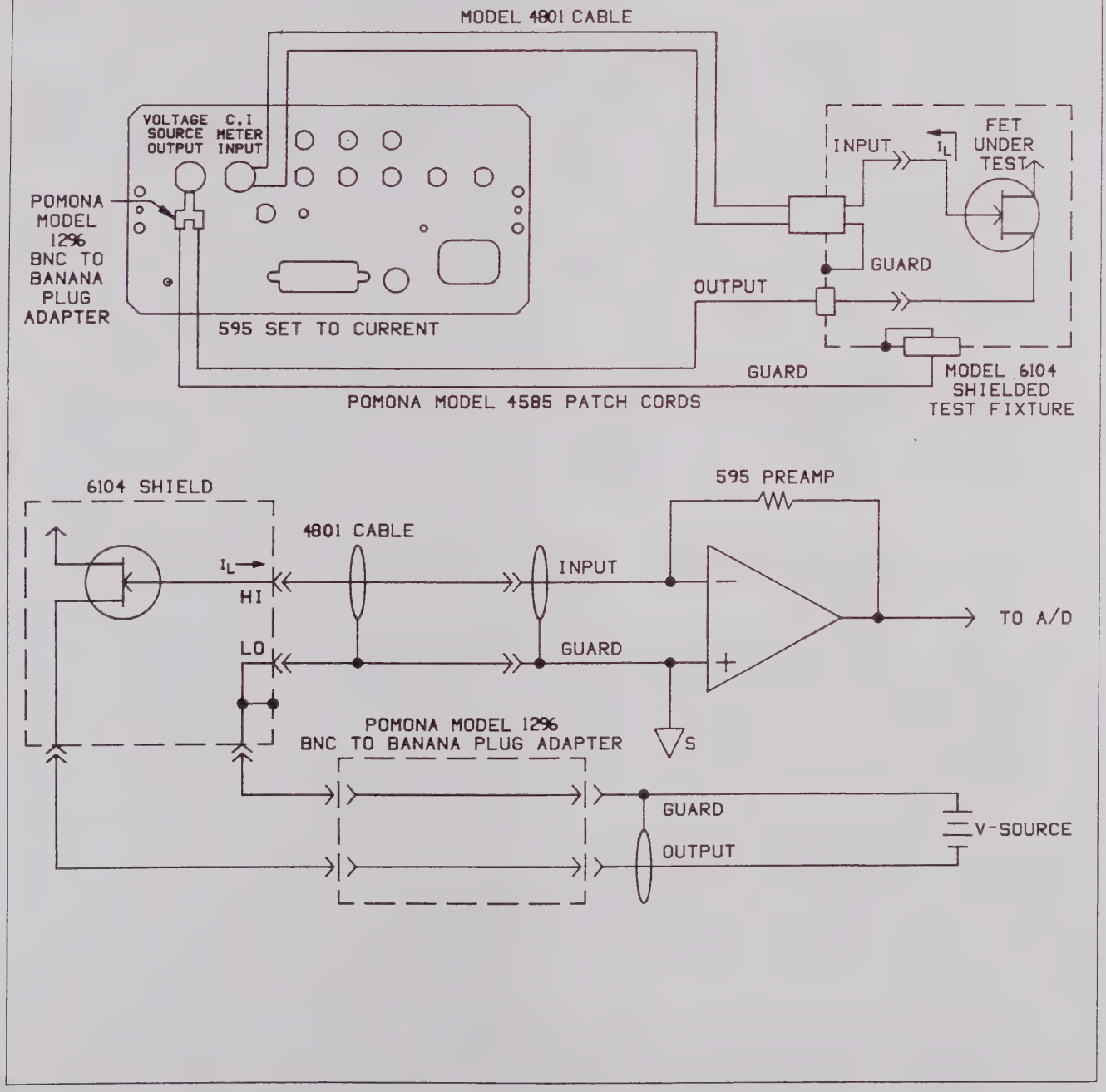


Figure 5-7. Leakage Current Measurement

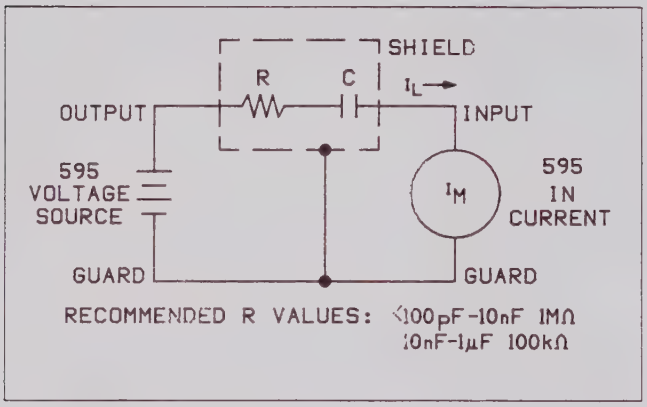


Figure 5-8. Capacitor Leakage Tests

5.3 APPLICATIONS OF THE CAPACITANCE FUNCTION

The Model 595 has been optimized for the measurement of quasistatic capacitance. This measurement is most commonly made on silicon MOS capacitors. The following discussion will thus focus primarily on MOS devices, however, much of the information presented can also be applied to measurements of other types of capacitors.

5.3.1 Considerations for Capacitance Measurements

The method used by the Model 595 to measure quasistatic capacitance is described in Section 7, Principles of Operation. Basically, the method consists of applying a voltage step across the capacitor under test and measuring the charge step induced on the capacitor. From the voltage step applied and the charge step measured, the capacitance value is determined according to the relation: $\Delta Q = C(\Delta V)$.

To make a valid measurement of differential capacitance on a MOS device, the voltage steps applied should be in the small signal range of the device under test. The small signal range is defined as the increment of voltage which is small enough such that the capacitance of the device does not vary significantly across the voltage increment.

Step voltages selectable on the Model 595 are 0.01, 0.02, 0.05, and 0.10V. Since full range capacitances from 200pF to 20nF may be measured, the full range charge steps induced are between 2pC and 2nC. From these charge measurements, 4½ digit readings are calculated. Therefore, very small charges, even as low as 0.1fC, can affect the capacitance reading. Furthermore, since measurement delay time can be varied from 0.07 to 199.99sec, leakage currents of femtoamps or less can cause appreciable errors in the capacitance measurement. To keep interference from stray currents low, insulation resistance in the device under test and the fixture must be kept very high. Paragraph 5.2.1 describes the procedure for verifying insulation resistance.

When current flows in addition to the displacement charge through the capacitor into the meter input of the Model 595, this current will cause an error in the capacitance reading. If the current is constant during the measurement, and the current is measured using Q/t, then the error in capacitance is given by:

C(error) = (Q/t)(Step time) / (Step V).

The range of capacitance which may be measured is consequently reduced by C(error).

Note that the capacitance reading can be corrected for the effect of constant current error sources by the use of the corrected capacitance feature. See paragraph 5.3.4 for guidelines on the proper use of this feature.

5.3.2 Characterizing the MOS Capacitor in Depletion and Accumulation

MOS capacitors come in many varieties, according to the application for which they are intended. For simplicity, the MOS construction assumed for this discussion will be a silicon substrate, on which is grown a thin insulating film such as SiO_2, which in turn has a conducting gate material deposited upon it. The capacitance of the device is measured from an ohmic contact on the silicon substrate to the conducting gate material. It is good measurement practice to connect the gate to the meter input, since there are typically fewer stray low impedance paths to other signal sources at this terminal.

The capacitance of the MOS device is voltage-dependent as illustrated in Figure 5-9. Three distinct regions of the CV curve are discernable: accumulation, depletion, and inversion. In addition to the material presented here regarding CV curves, many of the sources presented in the bibliography, paragraph 5.4 describe regions of the CV curve in detail.

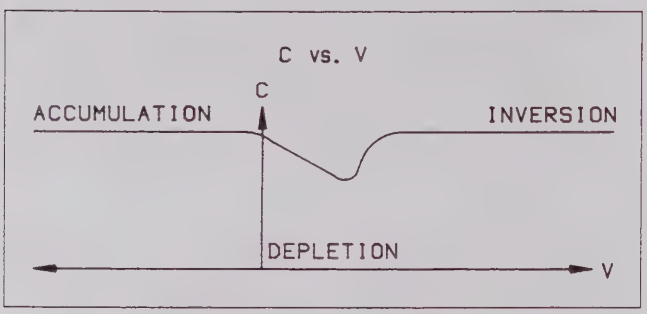


Figure 5-9. C vs. V Curve

In accumulation, majority carriers are attracted to the $Si\text{-}SiO_2$ interface. Since the majority carrier density is much higher than minority carrier density, the majority carriers determine the response of the device to a step in voltage. The charge exchange which satisfies the $\Delta Q = C \Delta V$ relation occurs at the interface, so the capacitance measured is C_{ox}, the oxide capacitance. C_{ox} is determined by the area of the gate, the thickness of the oxide, and the dielectric constant of the insulating film.

In depletion, the majority carriers are repelled from the interface creating a region depleted of majority carriers. This is referred to as the depletion or space charge region. The width of this region is determined by the number of impurity atoms which must give up majority carriers to satisfy the charge exchange. The charge exchange occurs at the edge of the depletion region. Effectively, then, there is a depletion layer capacitance, C_D, in series with C_{ox}, so that the total capacitance is lower in depletion. Since the charge exchange is dominated by this exchange of majority carriers, device response in depletion is fast (even microseconds or less).

The remaining MOS CV curve region, inversion, will be discussed separately in paragraph 5.3.3.

To Measure C_{ox}: Lift the probe or disconnect the device as close to the device as possible. The capacitance measured under this condition is the fixture offset. Press SUPPRESS to make measurements relative to this value. The Q/t value obtained will now be the fixture leakage. If significant fixture leakage is suspected, it may be useful to measure Q/t versus V in order to determine whether the leakage is resistive or constant. Now connect the probe and bias the device into accumulation. The value of the capacitance measured at this bias is C_{ox}. Often, a curve normalized to C_{ox} is desired, so the C_{ox} value would be stored as C_O. Then when a curve is measured, using C/C_O will yield C/C_{ox}.

Remember that the voltage source output is applied to the substrate and the gate is at virtual ground. This means that the voltage source output is equal to minus the gate bias voltage. Plotting with the Model 595 set to code 43 allows the voltage axis of a digital plot to be inverted so that the curve has the usual capacitance versus gate bias shape.

In accumulation or depletion, the capacitive displacement charge will transfer long before Q/t is measured. Q/t will therefore represent DC error currents from the fixture and the device, such as oxide leakage. As with fixture leakage alone, plotting Q/t versus V can be helpful in diagnosing Dc error current sources. It is important to note the level of DC error currents in depletion and accumulation for later use in determining conditions for equilibrium measurement in the inversion region.

5.3.3 Characterizing the MOS Capacitor in Inversion

In inversion, majority carriers are depleted from the $Si\text{-}SiO_2$ interface as in depletion. However, once the Fermi level at the interface reaches the intrinsic Fermi level, a layer of minority carriers will begin to form at the interface. Formation of the layer is usually dependent upon charge transfer through traps in the depletion layer at room temperature.

This process can be modeled as a generation conductance (G_{gr}) in series with an inversion layer capacitance C_I. The series combination is then in parallel with the depletion capacitance, as shown in Figure 5-10. C_I is much larger than C_D, so that, given sufficient time to respond, C_I will dominate the response and C_D will be unaffected. The inversion layer time constant will be on the order of milliseconds to tens of seconds, depending on the device.

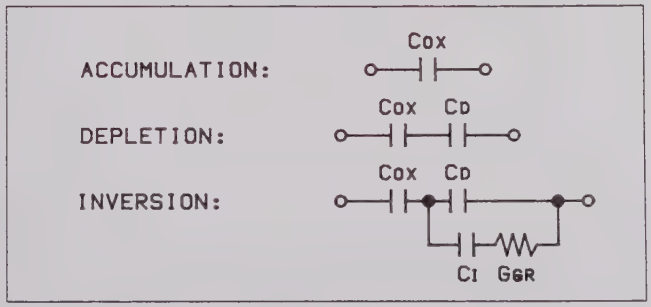


Figure 5-10. Equivalent Circuits of the MOS Capacitor

A direct observation of the charging of C_f can be made using the inversion decay program below:

```
10 ! !!!!!!!!!!!!!!!!!!!!!!!!!
20 ! INVERSION DECAY PROGRAM
30 ! !!!!!!!!!!!!!!!!!!!!!!!!!
40 ! THIS PROGRAM IS USED TO
50 ! OBSERVE THE RESPONSE OF
60 ! A CAPACITOR TO A STEP
70 ! IN VOLTAGE. Q/t MONITORS
80 ! THE CHARGING CURRENT
90 ! FOR 100 SECONDS AND PLOTS
100 ! !!!!!!!!!!!!!!!!!!!!!!!!!
110 DIM C(100),D(100),T(100)
120 DIM A$[35]
130 CLEAR
140 DISP "INPUT OPTIONAL TITLE";@ INPUT
T$
150 DISP "INPUT NEW VOLTAGE";
160 INPUT V1
170 !    ONE Q/t READING
180 ! IS TAKEN EACH SECOND.
190 ! DELAY TIME OF 0.43 SEC
200 ! ALLOWS FOR HP-85 TIME
210 ! AND 2 STEPS PER RDG.
220 ! 595 IEEE ADDRESS IS 28
230 DISP "SECONDS","Q/t"
240 OUTPUT 728 ;"F0Z0I.43W1Q1G1T4X"
250 ENTER 728 ; C,V,D
260 D(0)=D @ T(0)=0
270 ! NEW VOLTAGE IS SENT HERE
280 OUTPUT 728 ;"V"&VAL$(V1)&"X"
290 FOR X=1 TO 100
300 ENTER 728 ; C,V,D
310 D(X)=D @ T(X)=X
320 DISP T(X),D(X)
330 NEXT X
340 ! PLOT ROUTINE
350 GCLEAR @ CLEAR
360 DISP "PLOTTER ADDRESS(1 FOR CRT)";@
INPUT P
370 DISP "INPUT LOW Q/t,HIGH Q/t FOR GRA
PH";@ INPUT R0,R1
380 PLOTTER IS P @ PEN 1
390 SCALE 0,100,R0,R1
400 IF P<>1 THEN 460
410 PRINT T$
420 PRINT "HIGH=";R1*1000000000;"nA"
430 PRINT "LOW=";R0*1000000000;"nA"
440 PRINT "Q/t VS. t FOR 100 SECONDS"
450 PRINT "NEW VOLTAGE IS ";V1;"VOLTS"
460 DISP "INPUT Y TO PLOT GRID";@ INPUT
X$@ IF X$<>"Y" THEN 530
470 FOR Y=R0 TO R1 STEP (R1-R0)/10
480 XAXIS Y
490 NEXT Y
500 FOR X=0 TO 100 STEP 10
510 YAXIS X
520 NEXT X
530 ! PLOT Q/t VS t FOR 1 STEP
540 MOVE 0,D(0)
550 FOR X=1 TO 100
560 DRAW T(X),D(X)
570 NEXT X
580 PEN 0
590 IF P<>1 THEN 630
600 GRAPH
610 COPY
620 PRINT @ PRINT @ PRINT @ PRINT
630 CLEAR
640 DISP "TYPE 'D' IF DONE WITH TESTING"
;@ INPUT X$
650 IF X$<>"D" THEN 150
660 DISP "DONE"
670 END
```

The program applies a new voltage to the device in the DC waveform and monitors the charging response using Q/t for 100sec. As C_f charges, current flows through G_{gr} and is measured by Q/t. When Q/t has settled to the DC leakage level of the system, C_f has fully charged and equilibrium has been achieved.

The decay observation can be used with a small voltage step to find the delay time needed for an equilibrium square wave capacitance measurement. It can also be used when first biasing the device into inversion to determine when the device has equilibrated to the new bias voltage before beginning measurement. The device response to a large change in bias voltage in inversion can be accelerated by exposing the capacitor momentarily to light. The light generates a large number of carriers at the edges of the gate which contribute to the inversion layer charge, circumventing G_{gr} and the long time constant.

5.3.4 Determining Delay Time for Equilibrium Measurement

The delay time necessary to obtain an equilibrium measurement is a key parameter of the MOS characterization. This value can be determined for either the square wave or the staircase waveform. The criteria used to identify equilibrium are:

1. The quasistatic capacitance value in the inversion region rises from the depletion value to approach C_{ox}.
2. The value of Q/t is at the DC leakage level of the system, indicating that at the end of the capacitance measurement the device has completed its charging response to the voltage step.

Using the square-wave waveform with the voltage source set to bias the device into inversion, the delay time can be varied for a specific size and polarity of step V to find the minimum value which will meet the above criteria. A program automating the search for equilibrium is presented below. The program will plot both C and Q/t versus delay time as the delay time is varied. Figure 5-11 shows an example plot. Corrected capacitance may be used to cancel the effects of leakage, but the results must be carefully interpreted. Any corrected capacitance readings taken when non-equilibrium Q/t flows will be invalid quantitatively. Paragraph 5.3.5 will describe use of corrected capacitance further.

In order to make an equilibrium staircase capacitance measurement, the delay time must also be long enough so that the accumulated residual decay of past steps is negligible. Otherwise, the level of equilibrium will actually decrease as the staircase proceeds. See paragraph 5.3.5 for a discussion of non-equilibrium in the staircase waveform.

```
10 ! !!!!!!!!!!!!!!!!!!!!!!!!!!!
20 ! C&Q/t VS. DELAY TIME PROG
30 ! !!!!!!!!!!!!!!!!!!!!!!!!!!!
40 ! THIS PROGRAM IS USED TO
50 ! MEASURE C & Q/t WITH A
60 ! SQUARE WAVE WHILE VARYING
70 ! DELAY TIME AND PLOT DATA.
80 ! !!!!!!!!!!!!!!!!!!!!!!!!!!!
90 IMAGE DDD.DD,2X,D.DDDDE,2X,D.DDDE
100 DIM C(100),Q(100),T(100)
110 DIM A$[35]
120 CLEAR
130 DISP "INPUT OPTIONAL TITLE";
140 INPUT T$
150 DISP "INPUT Tmax";
160 INPUT T0
170 OUTPUT 728 ;"F0Z0P0W2G1T4X"
180 PRINT T$ @ PRINT
190 PRINT "  DELAY CAPACITANCE       Q/t"
200 FOR X=1 TO 20
210 T=T0*.1*10^((X-10)/10)
220 IF T<.07 THEN T=.07
230 IF T>199.99 THEN T=199.99
240 OUTPUT 728 ;"I"&VAL$(T)&"X"
250 WAIT 1000*T+1000
260 ENTER 728 ; C,V,Q
270 PRINT USING 90 ; T,C,Q
280 C(X)=C @ Q(X)=Q @ T(X)=T
290 NEXT X
300 ! PLOT C VS t
310 GCLEAR @ CLEAR
320 DISP "PLOTTER ADDRESS(1 FOR CRT)";
330 INPUT P
340 DISP "INPUT LOW C,HIGH C FOR GRAPH";
350 INPUT C0,C1
360 DISP "INPUT LOW Q/t,HIGH Q/t FOR GRA
PH";
370 INPUT Q0,Q1
380 PLOTTER IS P @ PEN 1
390 SCALE 0,T0,C0,C1
400 IF P<>1 THEN 460
410 PRINT @ PRINT "LOW C=";C0*1.E12;"pF"
420 PRINT "HIGH C=";C1*1.E12;"pF"
430 PRINT "LOW Q/t=";Q0*1000000000;"nA"
440 PRINT "HIGH Q/t=";Q1*1000000000;"nA"
450 PRINT @ PRINT "MAX DELAY TIME ON PLO
T=";T0;"s"
460 DISP "INPUT Y TO PLOT GRID";
470 INPUT X$@ IF X$<>"Y" THEN 560
480 ! PLOT GRID
490 FOR Y=C0 TO C1 STEP (C1-C0)/10
500 XAXIS Y
510 NEXT Y
520 FOR X=0 TO T0 STEP T0/10
530 YAXIS X
540 NEXT X
550 ! PLOT C VS DELAY TIME
560 MOVE T(1),C(1)
570 FOR X=2 TO 20
580 DRAW T(X),C(X)
590 NEXT X
600 ! PLOT Q/t VS DELAY TIME
610 SCALE 0,T0,Q0,Q1
620 MOVE T(1),Q(1)
630 FOR X=2 TO 20
640 DRAW T(X),Q(X)
650 NEXT X
660 PEN 0
670 IF P<>1 THEN 720
680 GRAPH
690 COPY
700 PRINT @ PRINT @ PRINT @ PRINT
710 CLEAR
720 DISP "TYPE 'D' IF DONE WITH TESTING"
;@ INPUT X$
730 IF X$<>"D" THEN 130
740 DISP "DONE"
750 END
```

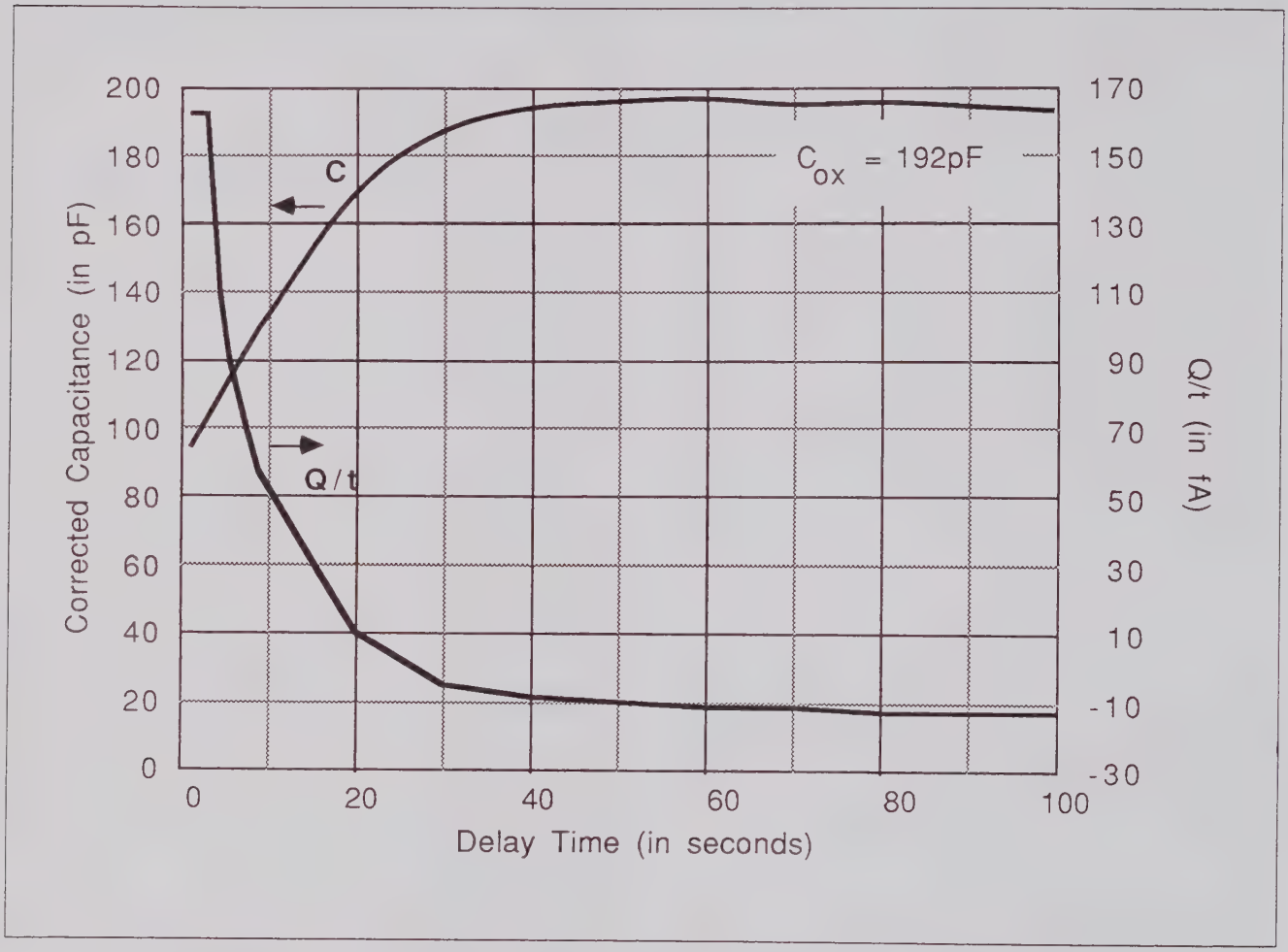


Figure 5-11. Recognizing Equilibrium Using C and Q/t vs. Delay Time: Inversion: Substrate Voltage = +8V, Squarewave Test Signal = +0.02V

5.3.5 MOS Non-equilibrium and Proper Use of the Corrected Capacitance Program

The corrected capacitance feature corrects for errors in capacitance measurements due to stray currents which are constant during the measurement. It combines capacitance and Q/t readings based on the assumption that Q/t is due to DC currents only, and generates a corrected capacitance reading. If Q/t is not solely due to DC currents, as when the device is in non-equilibrium, then the assumption is false and erroneous corrected capacitance readings will result.

Figure 3-3 shows the charge waveform of the device under test and the three charge measurements which are made on that waveform. From the three determinations of charge, the quantities of capacitance, Q/t, and corrected capacitance are calculated according the the equations presented in the figure.

A dramatic example of the magnitude of capacitance error which can be corrected for is shown in Figure 5-12. It shows the corrected and uncorrected curves of a 98.8pF polystyrene capacitor connected in parallel with a 100GΩ resistor. The curve was generated by taking one 0.10V step every 0.10sec. The slant of the uncorrected curve would affect any quasistatic CV curve, including those generated by the ramp or Q-V methods. Without correction, the error dominates the measured curve. The corrected curve, however, shows no observable effect of the resistor on the measured capacitance.

Another example of the proper use of the capacitance correction program is presented in Figure 5-13 (Equilibrium curve). This curve was generated from a MOS capacitor having n-type silicon and long lifetime (10-15μsec). To illustrate the very slow staircase practical with the Model 595, the curve was measured over a 5½ hour period, taking one 0.05V step every 100sec. The capacitance has been corrected for leakage, normalized to 195.16pF using C/C_O, and filtered using Filter 2.

An example of nonequilibrium is shown in Figures 5-13. The curves were taken on the same device as used for equilibrium, but with a much faster staircase. Step V was 0.05V and delay time was 0.5sec.

The bottom graph illustrates that when staircasing towards inversion, the device is not in equilibrium. When a voltage step is applied across the device, C_D initially supplies the charge necessary to satisfy the $\Delta Q = C\,\Delta V$ relation. Then C_I, which is larger, gradually charges through G_{gr}, allowing C_D to return to its previous state. If C_I never has time to charge, then repeated steps drive the capacitor into deep depletion. Deep depletion is simply the effect of changing the gate bias so quickly from the depletion region to the inversion region that the inversion layer cannot appreciably build up and C_D satisfies the majority of charge exchange. With each step, the space charge region grows wider, C_D grows smaller, and the measured capacitance decreases.

The curve in the bottom graph of Figure 5-13 for a staircase from inversion back toward depletion shows a response resembling equilibrium. From the Q/t curves of the top graph, however, it is apparent that this is not an equilibrium curve, since current is still flowing. The current flowing is attempting to charge C_I. Since that process is still ongoing with each voltage step, it is apparent that C_D must be providing the initial charge exchange. During each step toward depletion in which C_D must supply charge that C_I cannot, the depletion width is reduced. This is observable on the right side of graph A as a gradual rise in capacitance to C_{ox}. When the capacitance has returned to C_{ox}, the depletion width has been reduced to so little that C_D in series with C_{ox} is approximately C_{ox}. As the voltage bias nears depletion, the conditions that allow inversion to occur (and allow C_I to remain charged) cease to exist. G_{gr} will increase, discharging C_I, and the curve will merge with the normal depletion curve.

Notice that the value of Q/t is lower for the staircase toward inversion than for the staircase from inversion toward depletion. This illustrates that G_{gr} is direction dependent. The reason is that different processes are responsible for the charge exchange depending on the staircase direction. The process involved when changing bias from inversion toward depletion is faster, so the effective value of G_{gr} in that direction is lower.

The top graph of Figure 5-13 shows the Q/t vs. V curves for the same staircase. It is clear from these curves that neither direction of the curve is a true equilibrium measurement because the level of Q/t rises from the DC leakage level of the system in inversion. The higher level of Q/t in the direction from inversion toward depletion agrees with the hypothesis that G_{gr} is lower in this direction.

Figure 5-14 shows what happens when the corrected capacitance program is inappropriately used on this curve. It is improper to use correction in this case because nonequilibrium currents are being measured by Q/t in inversion. When the Q/t value is used to generate the corrected capacitance value, not only the error capacitance due to DC leakage currents, but also the effective capacitance due to the current flowing through G_{gr} is subtracted from the capacitance reading. The result is an erroneous and meaningless corrected capacitance curve.

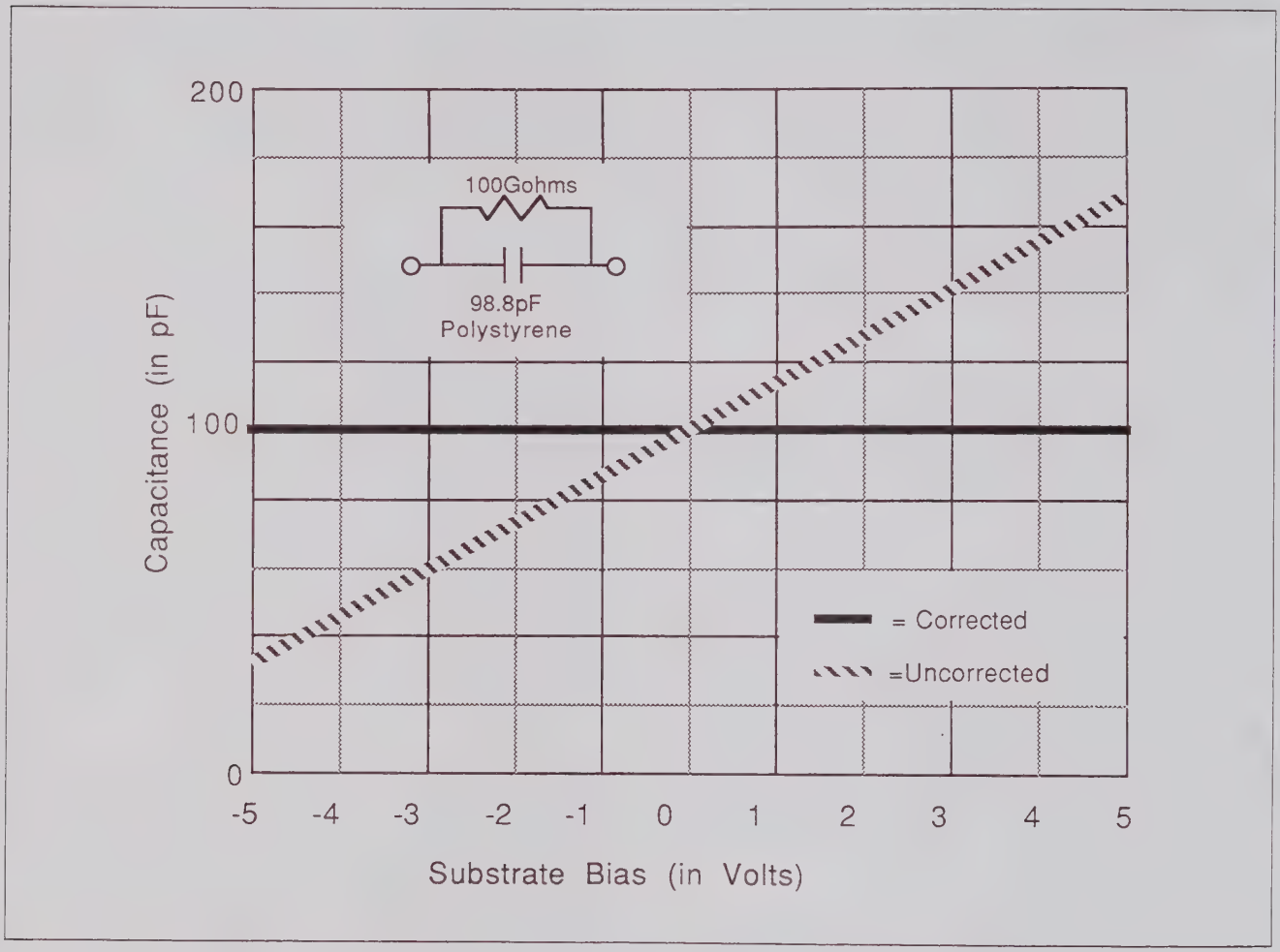


Figure 5-12. Corrected and Uncorrected CV Curves of a Simulated Leaky Capacitor
C(corrected) = C−(Q/t)(Step Time)/(V Step)

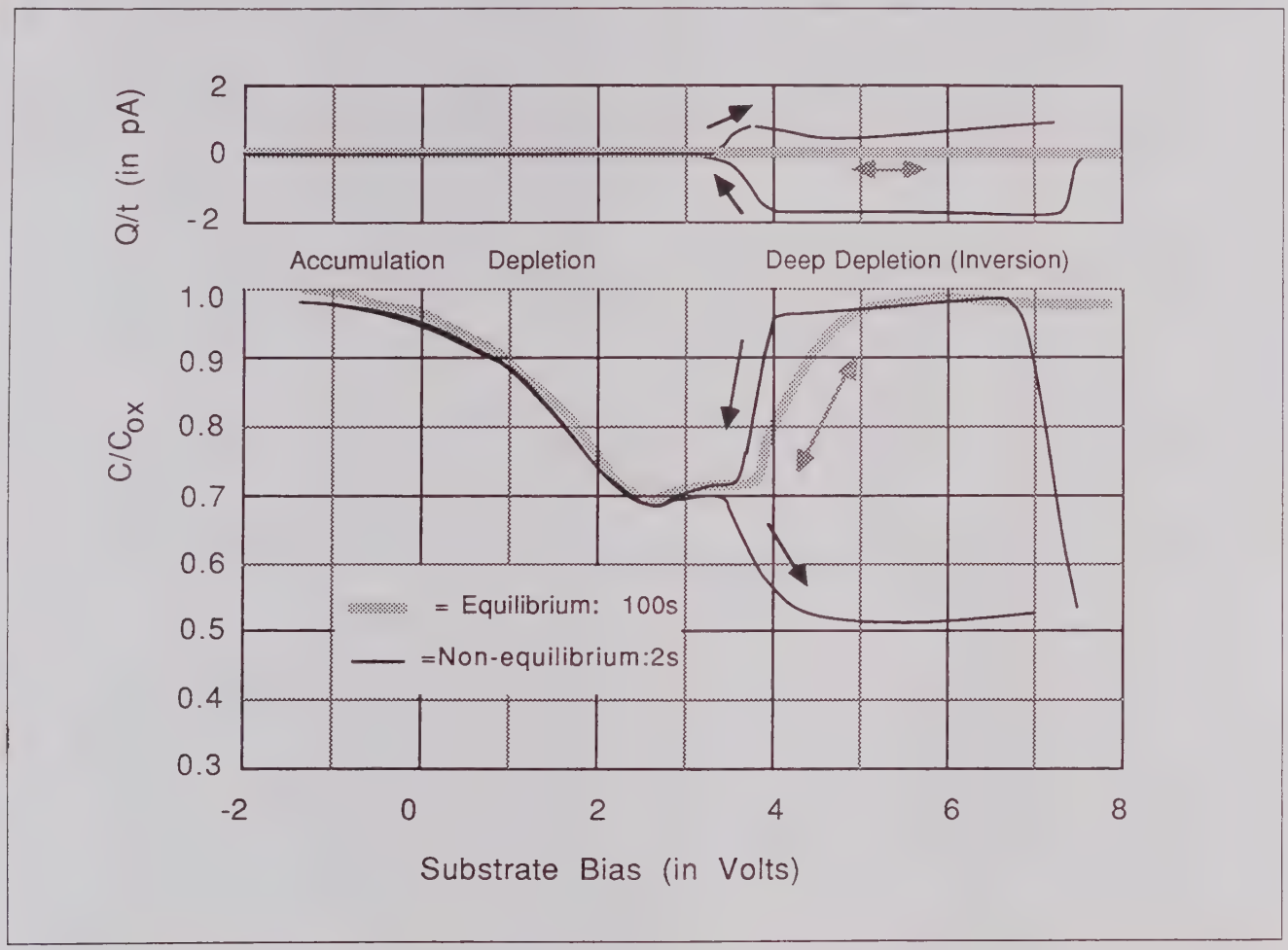


Figure 5-13. Recognizing Equilibrium Using C vs. V and Q/t vs. V

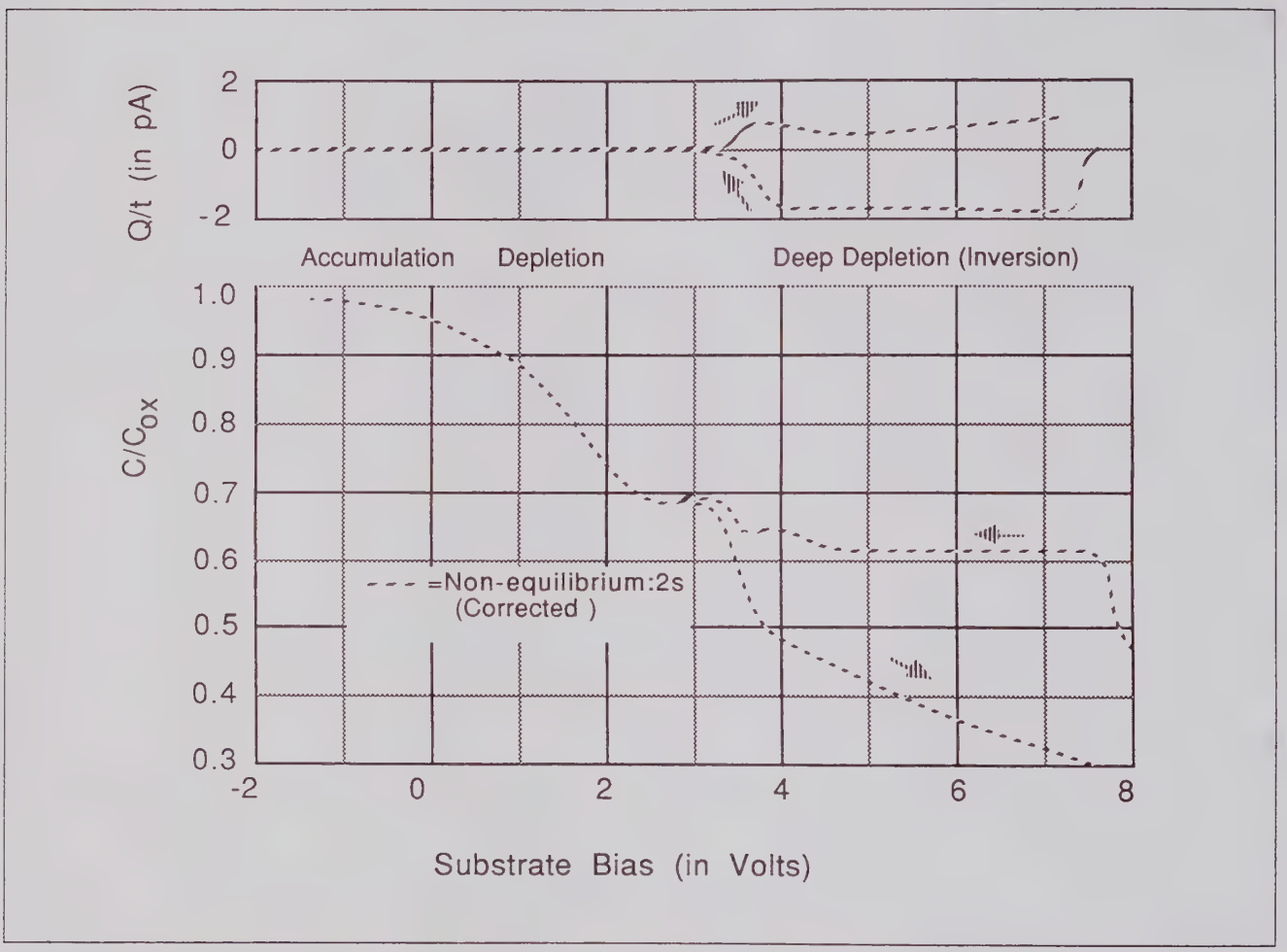


Figure 5-14. Misuse of Corrected Capacitance Program on Non-Equilibrium Curves

5.3.6 Comparison of the Feedback Charge Method with the Traditional Ramp Method

The traditional ramp method of measuring quasistatic capacitance originally proposed by Kuhn, Castagne, and Kerr (see Bibliography, paragraph 5.4) has been used extensively for MOS characterization. In the ramp method, shown in Figure 5-15, the device under test (DUT) is connected between a linear ramp generator, dV/dt, and a feedback current amplifier. The current flowing through the DUT is thus measured by observing V_{out} . If the DUT were an ideal capacitor, this current would be the capacitor displacement current: $I = C_x(dV/dt)$.

For a capacitance of 100pF and a ramp rate of 0.1V/sec, a current of 10pA would be measured. Of course, for an actual MOS capacitor, any additional current due to leakage or non-equilibrium behavior would also be measured. The inability to distinguish between displacement current and other currents is a major limitation of the ramp method when the DUT or the system has significant leakage or when the ramp rate is very low.

The ramp method has several other limitations. The circuit is that of a differentiator. This means that any noise appearing across the DUT will be amplified by a gain of $(2\pi fC_xR_F)$. The frequency dependence of this gain makes the measurement particularly susceptible to interference that has high frequency components. A graph of gain vs. frequency is shown in Figure 5-16. Typical signal frequencies with this circuit are very low (below 1Hz). At these low frequencies the gain of the ramp method circuit decreases, further reducing the signal to noise ratio of the measurement. Also, feedback resistors needed to amplify low currents must be extremely large, perhaps 100GΩ or more. Resistors this large have poor temperature stability, high Johnson voltage noise, and long time constants when combined with the capacitance necessary to stabilize the circuit. Accuracy of the ramp method is limited by these and other effects to approximately 1 to 5% at low ramp rates.

The measurement method used by the Model 595 avoids many of the limitations of the ramp method and thereby achieves a more accurate measurement of quasistatic capacitance. Figure 5-16 shows some of the feedback charge method properties. With this method, a signal charge is measured, instead of a signal current as in the ramp method. Currents flowing into the integrator in addition to the signal charge can be measured independently using Q/t. The capacitance measurement can be corrected for the effect of error currents when it has been determined that the current is not due to non-equilibrium in the DUT. To correct for leakage with the ramp method, multiple curves would have to be taken using different ramp rates. If the conditions under which sequential curves are taken are sufficiently repeatable, then the DC current could be separated from the true signal current by solving simultaneous equations.

In the frequency range of interest, the circuit of the feedback charge method is not frequency-dependent. This is illustrated in Figure 5-16. The ratio of signal gain to noise gain for the circuit does not decrease when long delay times are used. Long delay times in the feedback charge method are roughly analogous to low ramp rates in the ramp method.

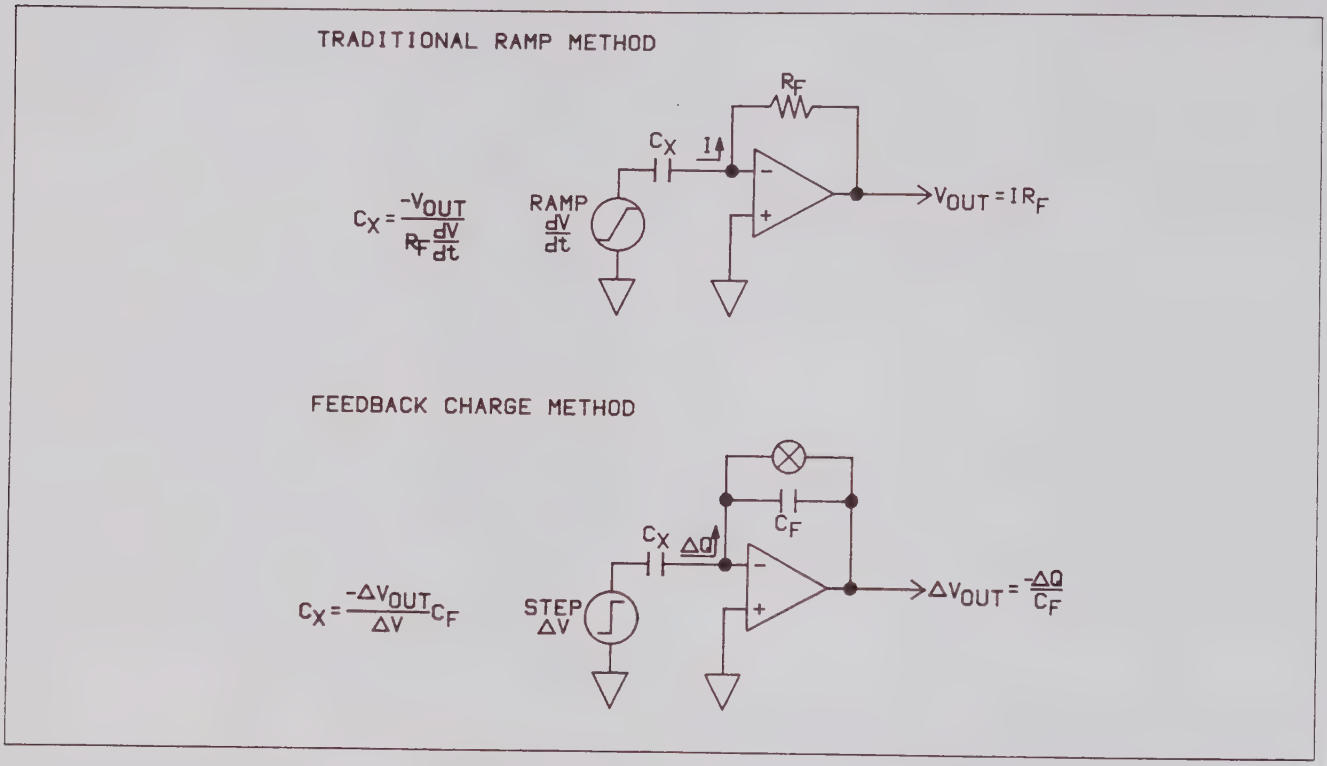


Figure 5-15. Comparison of Quasistatic CV Methods

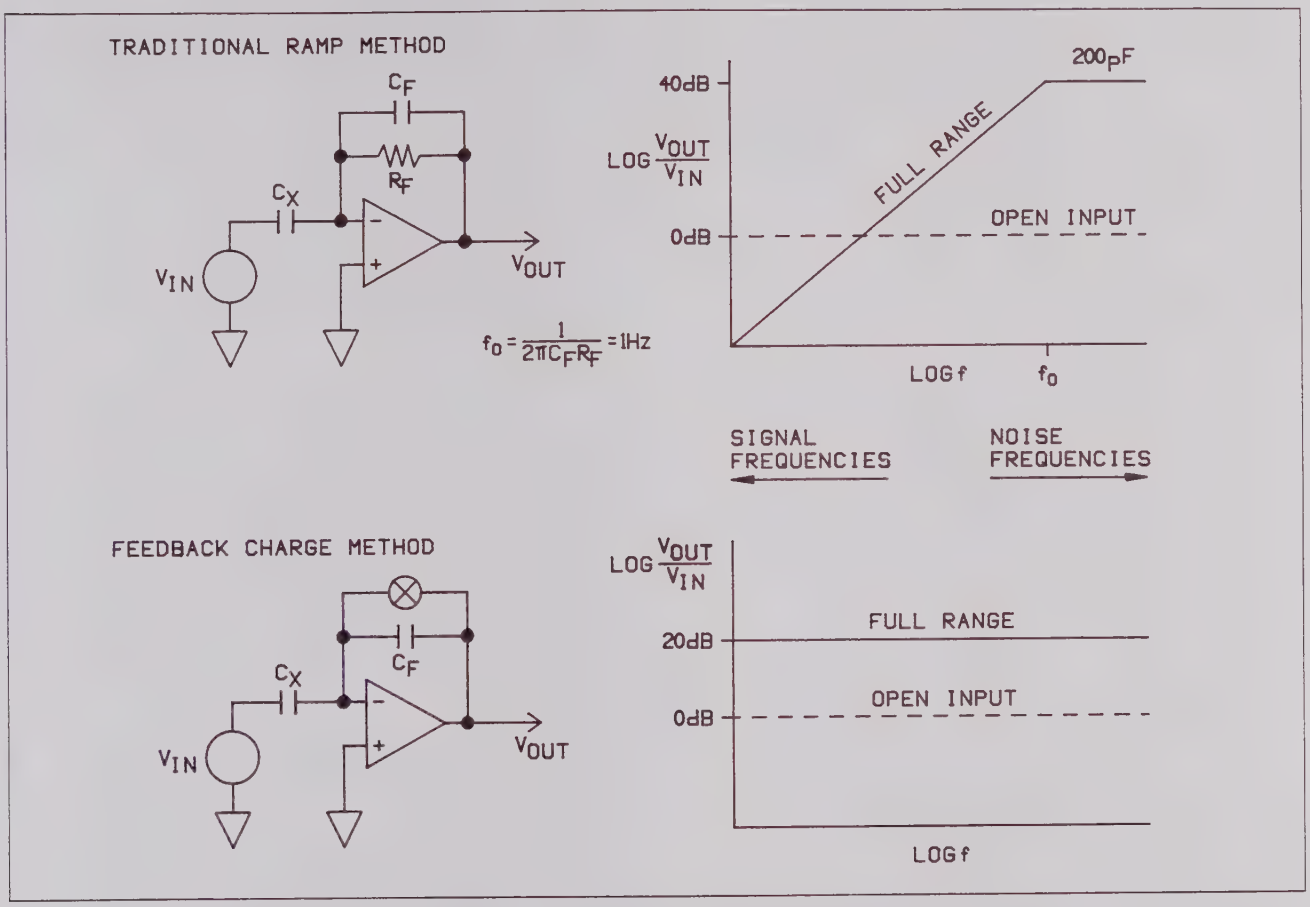


Figure 5-16. Frequency Response

5.3.7 Comparison of the Feedback Charge Method with the Static or Q-V Method

A method of measuring capacitance has been suggested by Ziegler and Klausmann, and expanded upon by Nicollian and Brews (see Bibliography, paragraph 5.4). This is known as the static method or the Q-V method. A diagram of the circuitry for this method is shown in Figure 5-17. As in the feedback charge method, one terminal of the DUT is connected to a DC voltage source capable of being incremented by ΔV. In this case, the other terminal is connected to a known capacitance C_s, whose value is independent of applied voltage. The DUT (C_x) and C_s form a capacitive divider. The midpoint of the divider is monitored by a high input impedance buffer. The voltage at the output of the buffer is therefore an indication of the charge on C_s, because $\Delta V_{out} = \Delta Q / C_s$. A delay time must be allowed between application of the voltage step and measurement of V_{out} to allow the DUT to come to equilibrium. Just as in the feedback charge method, the value of C_x is determined knowing ΔQ and the step ΔV: simply, $C_x = \Delta Q / (\Delta V - \Delta V_{out})$.

The feedback charge method and the Q-V method both determine capacitance by measuring the transfer of charge in the DUT in response to an increment in bias voltage. It is the way in which charge is measured that distinguishes the two methods. The voltage buffer used in Q-V must have high input impedance and low input bias current. For instance, if a 0.1V step is applied across a series combination of C_s and C_x totaling 100pF, a 10pC charge is transferred. If 100sec is required for C_x to come to equilibrium, then a leakage current of 1fA would cause a 1% error in the result. In addition, if the resistance in parallel with C_s (such as the buffer input resistance) were 100,000GΩ, the bleeding of charge off C_s would cause a 1% error for a 100sec delay.

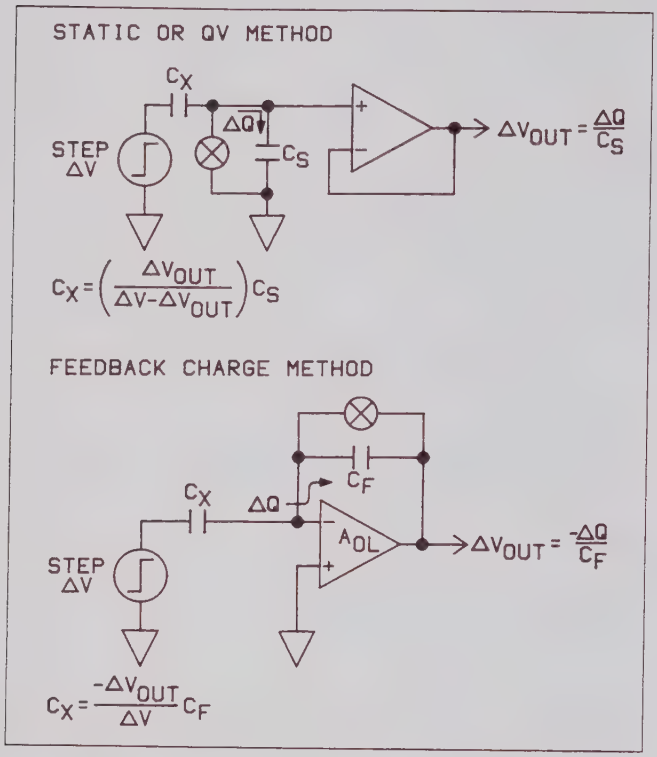


Figure 5-17. Comparison of Quasistatic CV Methods

Not only resistance, but also capacitance in parallel with C_s, such as the buffer input, cables, or fixturing will cause errors. The capacitance of a typical buffer input and one meter of coaxial or triaxial cable would be over 100pF. It can be difficult to reliably correct for this capacitance, although partial correction can be accomplished through guarding the input with V_{out} .

The use of the capacitive divider has other disadvantages. Because the increment in bias voltage is shared between C_s and C_x, the step measured in the buffer V_{out} is smaller than the bias step. This imposes a tradeoff in choosing C_s. If $C_s \ll C_x$, then the increment across C_x is small, so the charge transferred is small. Most of ΔV appears across C_s so V_{out} is easier to measure, but this means that errors caused by the buffer input impedance are greater. If $C_s \gg C_x$ then nearly all of ΔV appears across C_x, so more charge is transferred. The voltage change across C_s is small, which reduces buffer requirements, but the change in V_{out} may consequently be only microvolts, making measurement difficult. Usually, C_s is chosen to be nearly equal to C_x.

The feedback charge method, as the name implies, uses a feedback charge amplifier. The amplifier must still have low input current, but the requirement for high input resistance and low input capacitance is greatly reduced. The voltage at the input of the charge amplifier is now only V_{out} divided by the open loop gain of the amplifier A_{OL} (typically 100,000 or more). The voltage across the resistance and capacitance on the input is thereby reduced from volts to microvolts. This allows a significant simplification of fixture requirements in areas such as probes, connectors, and cables.

The DUT is referenced to the virtual ground input of the charge amplifier, so all of the bias voltage step appears across the device. This gives tighter control of the voltage applied to C_x. It also allows the value of C_f (analogous to C_s in Q-V) to be chosen to optimize gain, without affecting the voltage increment across C_x. C_f can then be chosen, for instance, to give a gain of 10 or more, instead of the typical 0.5 in Q-V. Higher gain relaxes requirements on the circuitry monitoring V_{out} , yielding more stable and less noisy results.

5.4 BIBLIOGRAPHY OF QUASISTATIC CV MEASUREMENTS AND RELATED TOPICS

I. Texts:

A. Nicollian, E.H. and Brews, J.R., MOS Physics and Technology. Wiley, New York (1982).

B. Sze, S.M., Physics of Semiconductor Devices. Wiley, New York (1969)

C. Grove, A.S., Physics and Technology of Semiconductor Devices. Wiley, New York (1967).

II. Articles and Papers:

A. Feedback Charge Method

1. Mego, T.J. "Improved Feedback Charge Method for Quasistatic CV Measurements in Semiconductors". Rev. Sci. Instr. **57**, 11 (1986).
2. Mego, T.J. "Improved Quasistatic CV Measurement Method for MOS". Solid State Technology, **29**, 11, S19-21 (1986).
2. Markgraf, W., Baumann, M., Beyer, A., Arst, P., Rennau, M., "Nutzung der statischen CU-Methode im Rahmen eines mikrorechnergesteuerten MOS-Messplatzes", Phys. d. Halbleiteroberflaeche. **15**, 73 (1984).

B. Q-V/Static Method

1. Ziegler, K. and Klausmann, E., "Static Technique for Precise Measurements of Surface Potential and Interface State Density in MOS Structures", Appl.Phys. Lett. **26**, 400 (1975).
2. Kirov, K., Alexsandrova, S. and Minchev, G., "Error in Surface State Determination Caused by Numerical Differentiation of Q-V Data", Solid State Electronics. **18**, 341 (1978).

C. Q-C Method and Simultaneous High-Low Frequency CV

1. Nicollian, E.H. and Brews, J.R., "Instrumentation and Analog Implementation of the Q-C Method for MOS Measurements", Solid State Electronics. **27**, 953 (1984).
2. Boulin, D.M., Brews, J.R. and Nicollian, E.H., "Digital Implementation of the Q-C Method for MOS Measurements", Solid State Electronics. **27**, 977 (1984).
3. Derbenwick, G.F., "Automated C-V and |Y|-w Curves for MOS Device Analysis", Sandia Report SAND80-1308 (1982).

D. Ramp Method

1. Kuhn, M., "A Quasistatic Technique for MOS C-V and Surface State Measurements", Solid State Electronics. **13**, 873 (1970).
2. Castagne, R., "De'termination de la densite' d'e'tats lents d'une capacite' me'tak-isolant semiconducteur par l'e'tude de la charge sous une tension croissant line 'airement", C.R.Acad. Sci. **267**, 866 (1968).
3. Kerr, D.R., "MIS Measurement Technique Utilizing Slow Voltage Ramps", Int.Conf.Properties and Use of MIS Structures, Grenoble, France, 303 (1969).
4. Castagne, R. and Vapaille, A., "Description of the SiO_2-Si Interface Properties by Means of Very Low Frequency MOS Capacitance Measurements", Surface Science, **28**, 157 (1971).
5. Kuhn, M. and Nicollian, E.H., "Nonequilibrium Effects in Quasi-static MOS Measurements", J.Electrochem.Soc., **118**, 373 (1971).
6. Lopez, A.D., "Using the Quasistatic Method for MOS Measurements", Rev.Sci.Instr. **44**, 200 (1973).

E. Surface States/Interface States

1. Berglund, C.N., "Surface States at Steam-Grown Silicon-Silicon Dioxide Interfaces", IEEE Trans.Electron.Dev., **13**, 701 (1966).
2. DeClerck, G., "Characterization of Surface States at the Si-SiO_2 Interface", Nondestructive Evaluation of Semiconductor Materials and Devices (J.N. Zemel, ed.) Plenum Press, New York, p. 105 (1979).
3. Brews, J.R., "Correcting Interface-State Errors in MOS Doping Profile Determinations", J.Appl.Phys. **44**, 3228 (1973).

F. MOS Process Characterization

1. Zaininger, K.H. and Heiman, F.P., "The C-V Technique as an Analytical Tool", Solid State Technology. **13**:5-6 (1970).
2. McMillan, L., "MOS C-V Techniques for IC Process Control", Solid State Technology. **15**, 47 (1972).
3. Zerbst, M., "Relaxationseffekte an Halbeiter-Isolator-Grenzflaechen", Z.Angew.Phys. **22**, 30 (1966).

SECTION 6
PERFORMANCE VERIFICATION

6.1 INTRODUCTION

The procedures outlined in this section may be used to verify that the instrument is operating within the limits stated in the specifications at the front of this manual. Performance verification may be performed when the instrument is first received to ensure that no damage or misadjustment has occurred during shipment. Verification may also be performed whenever there is a question of instrument accuracy, or following calibration, if desired.

NOTE

If the instrument is still under warranty (less than one year from the date of shipment), and its performance falls outside the specified range, contact your Keithley representative or the factory to determine the correct course of action.

6.2 ENVIRONMENTAL CONDITIONS

Accuracy checks should be made at 18° to 28°C and at less than 70% relative humidity. However, if the input current is to be checked, do so at 23°C, ±1°C.

6.3 INITIAL CONDITIONS

The Model 595 must be turned on and allowed to warm up for at least two hours before beginning the verification procedures. (NOTE: Wait at least eight hours before attempting input current verification procedures.) If the instrument has been subject to extremes of temperature (outside the ranges specified in paragraph 6.2), additional time should be allowed for internal temperatures to reach normal operating temperature. Typically, it takes one additional hour to stabilize a unit that is 10°C (18°F) outside the specified temperature range.

NOTE

While rated accuracy is achieved after the two hour warm up period, input bias current may require additional time to come to its optimum level. Allow two hours for input bias current to settle to less than 10fA and eight hours to less than 5fA. It is preferable in sensitive applications to leave the unit on continuously.

6.4 RECOMMENDED TEST EQUIPMENT

Table 6-1 lists all test equipment required for verification. Alternate equipment may be used as long as the substitute equipment has specifications at least as good as those listed in the table.

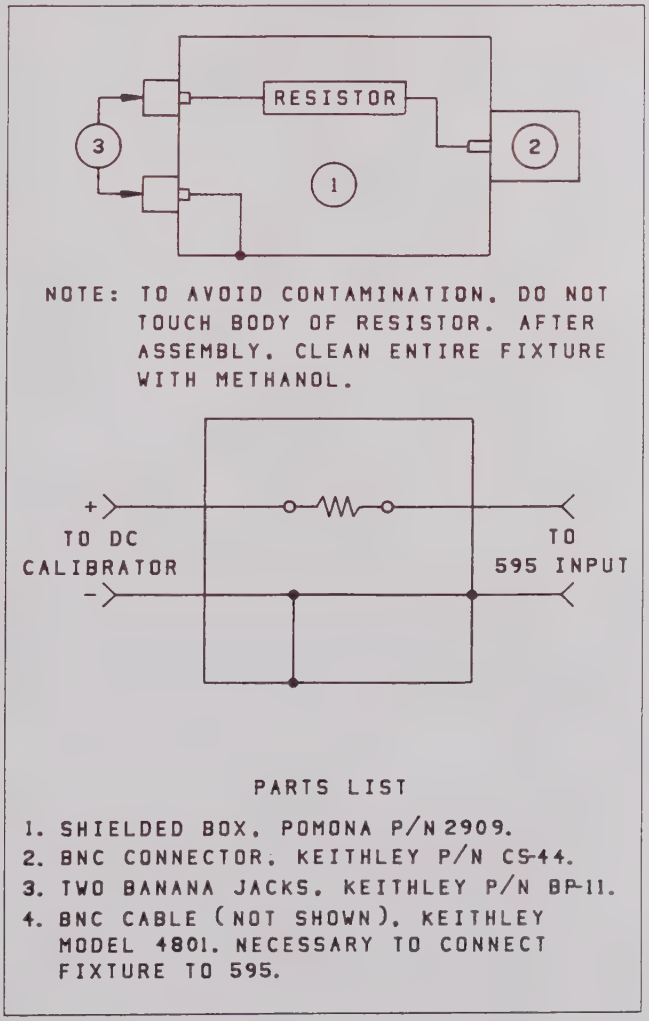

RESISTOR
3
2
1
NOTE: TO AVOID CONTAMINATION, DO NOT TOUCH BODY OF RESISTOR. AFTER ASSEMBLY, CLEAN ENTIRE FIXTURE WITH METHANOL.
+
TO DC CALIBRATOR
-
TO 595 INPUT
PARTS LIST
1. SHIELDED BOX, POMONA P/N 2909.
2. BNC CONNECTOR, KEITHLEY P/N CS-44.
3. TWO BANANA JACKS, KEITHLEY P/N BP-11.
4. BNC CABLE (NOT SHOWN), KEITHLEY MODEL 4801. NECESSARY TO CONNECT FIXTURE TO 595.

Figure 6-1. Test Fixture Construction

Table 6-1. Recommended Test Equipment for Performance Verification

Description	Specifications	Manufacturer and Model
DC Calibrator	0.19V, 1.9V, ±0.002%	Fluke; 343A
5½ Digit DMM	±0.015% DC Accuracy	Keithley; 197
Teraohmmeter	100MΩ, ±0.035% 1GΩ, ±0.05% 10GΩ, ±0.07% 100GΩ, ±0.08%	Guildline; 9520
Resistor	100MΩ, ±1%	Keithley; R-289-100M
Resistor	1GΩ, ±2%	Keithley; R-289-1G
Resistor	10GΩ, +0,−2%	Keithley; R-319-10G
Decade Resistor	10Ω-10MΩ, ±0.03%	ESI; DB-62
Characterized Capacitors	18nF, 1.8nF, 180pF	Keithley; 5955
Shielded Test Box		See Figure 6-1.
BNC Cable		Keithley; 4801 (supplied with 595)
BNC to Banana Plug Adapter		Pomona; 1269

NOTE

The verification limits in this section do not include test equipment tolerance.

A shielded test fixture will be necessary for the current verification procedure. Construction of this shield is illustrated in Figure 6-1.

6.5 VERIFICATION PROCEDURES

The following paragraphs contain procedures for verifying instrument accuracy of the current and capacitance functions including Q/t. Procedures to verify the input current and internal voltage source accuracy are also included. These procedures are intended for use only by qualified personnel using accurate and reliable test equipment. If the instrument is out of specification, refer to Section 8 for calibration procedures, unless the unit is still under warranty.

WARNING

The maximum common mode voltage (voltage between GUARD [input low] and chassis ground) is 30V. Exceeding this value may create a shock hazard. Some of the procedures in this section may expose you to dangerous voltages. Use standard safety precautions when such dangerous voltages are encountered.

CAUTION

The maximum voltage between the INPUT and GUARD terminals is 30V. Instrument damage may occur if this value is exceeded.

6.5.1 Input Current Verification

Perform input current verification as follows:

NOTE

The following procedure must be performed at an ambient temperature of 23°C, ±1°C.

1. Disconnect all cables from the Model 595 input.
2. Place the input cap supplied with the instrument on the METER INPUT BNC connector.
3. Select the CURRENT function and the 20pA range. Then enable ZERO CHECK and perform zero CORRect.
4. Using Program FILTER, select Filter 3.
5. Disable ZERO CHECK and allow the reading to stabilize (typically one minute).
6. Verify that the display reads 0.000 ±6 counts.

6.5.2 Current Verification

Perform current verification as follows:

1. Enable ZERO CHECK and select the CURRENT function.
2. Select the 200μA range and Filter 3.
3. Connect the DC calibrator and decade resistance box to the instrument as shown in Figure 6-2.
4. With ZERO CHECK still enabled, verify that the display reads 00.00μA ±1 count. If not, perform CORRect.
5. Apply the correct input by setting the DC calibrator and decade box to the values listed in Table 6-2.
6. Disable ZERO CHECK. Check to see that the reading is within the limits listed in Table 6-2.
7. Repeat the procedure for the 200nA -20μA ranges, as listed in Table 6-2. Be sure to set both the decade box and DC calibrator to the values listed.
8. Using the teraohmmeter, measure the actual value of the 100MΩ resistor and record its value in the appropriate space in the table.

Table 6-2. Limits for Current Verification

Range	Verification Current	DC Calibrator* Voltage	Resistance Value*	Allowable Reading (18°C to 28°C
200μA	190μA	19.000V	100kΩ	189.80 to 190.20
20μA	19μA	19.000V	1MΩ	18.977 to 19.023
2μA	1.9μA	19.000V	10MΩ	1.8980 to 1.9020
200nA	190nA	1.900V	10MΩ	189.77 to 190.23
20nA	19nA	(1.9V) _____	(100MΩ) _____	18.952 to 19.048
2nA	1.9nA	(1.9V) _____	(1GΩ) _____	1.8947 to 1.9053
200pA	190pA	(1.9V) _____	(10GΩ)_____	187.13 to 192.87
20pA	19pA	(1.9V) _____	(100GΩ) _____	18.701 to 19.299

*Values in parenthesis are nominal values. See text for methods to determine these values.

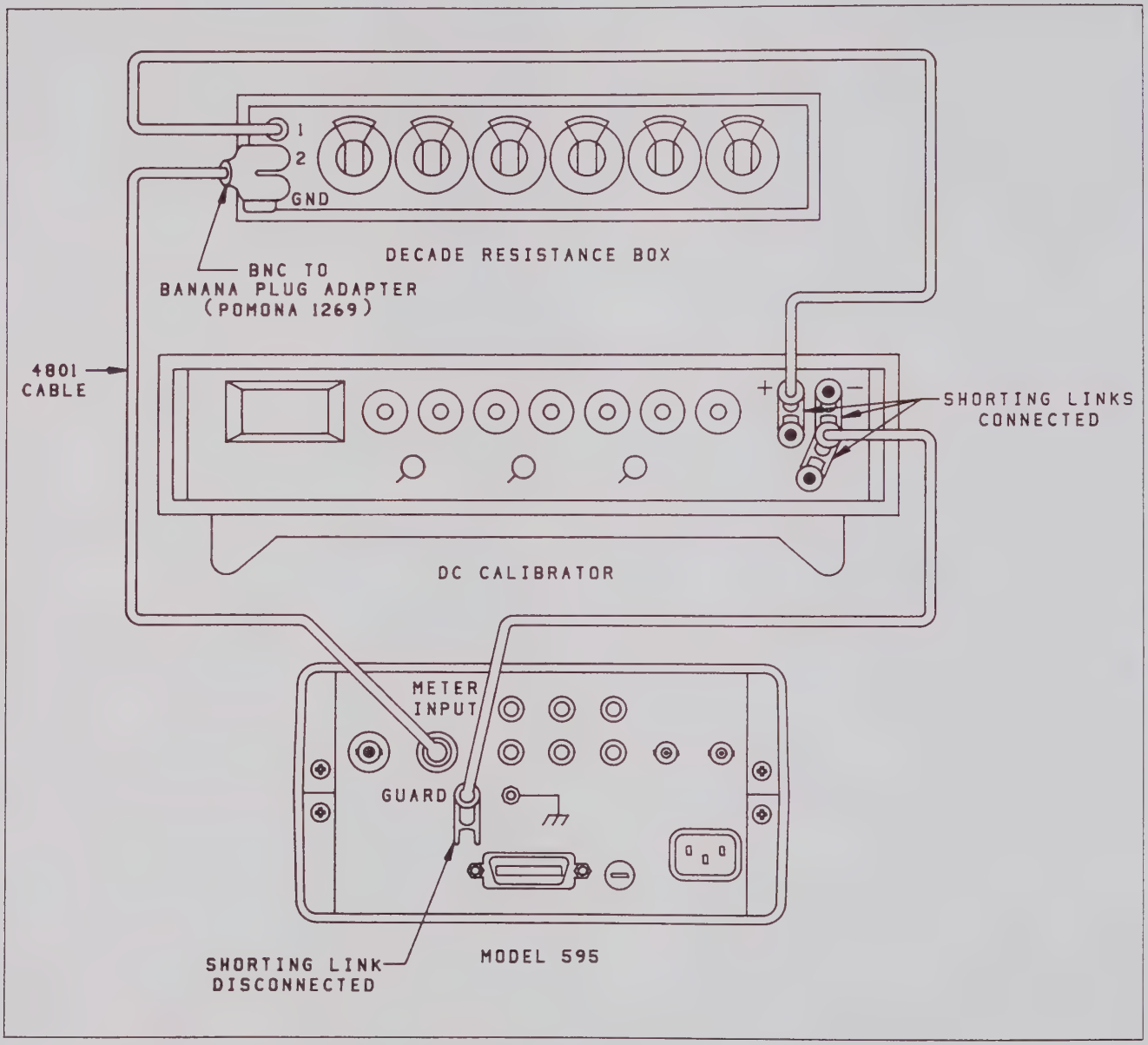


Figure 6-2. Setup for Current Verification (200nA to 200μA Ranges)

NOTE

Do not touch the body of the resistor to avoid contamination which could give erroneous results.

9. Calculate the actual calibrator voltage by multiplying the measured resistor value by the calibration current for that range. For example, if the actual resistance is 99MΩ, the required calibrator voltage is $V=(99 \times 10^6)(19 \times 10^{-9}) = 1.881V$. Write the calculated value in Table 6-2.
10. Set the calibrator voltage to the exact value obtained in step 9.
11. Place the instrument on the 20nA range and enable ZERO CHECK. Verify that the display shows 0.000nA ±1 count. If not, perform CORRect.
12. Mount the 100MΩ resistor in the shielded fixture (construction is covered in Figure 6-1) and connect the fixture to the instrument, as shown in Figure 6-3.
13. Disable ZERO CHECK and verify that the reading is within the limits given in Table 6-2. Enable ZERO CHECK.
14. Repeat steps 8 through 13 for the 20pA - 2nA ranges. For each range, measure the actual resistor value and calculate the calibration voltage using that value along with the required calibration current.

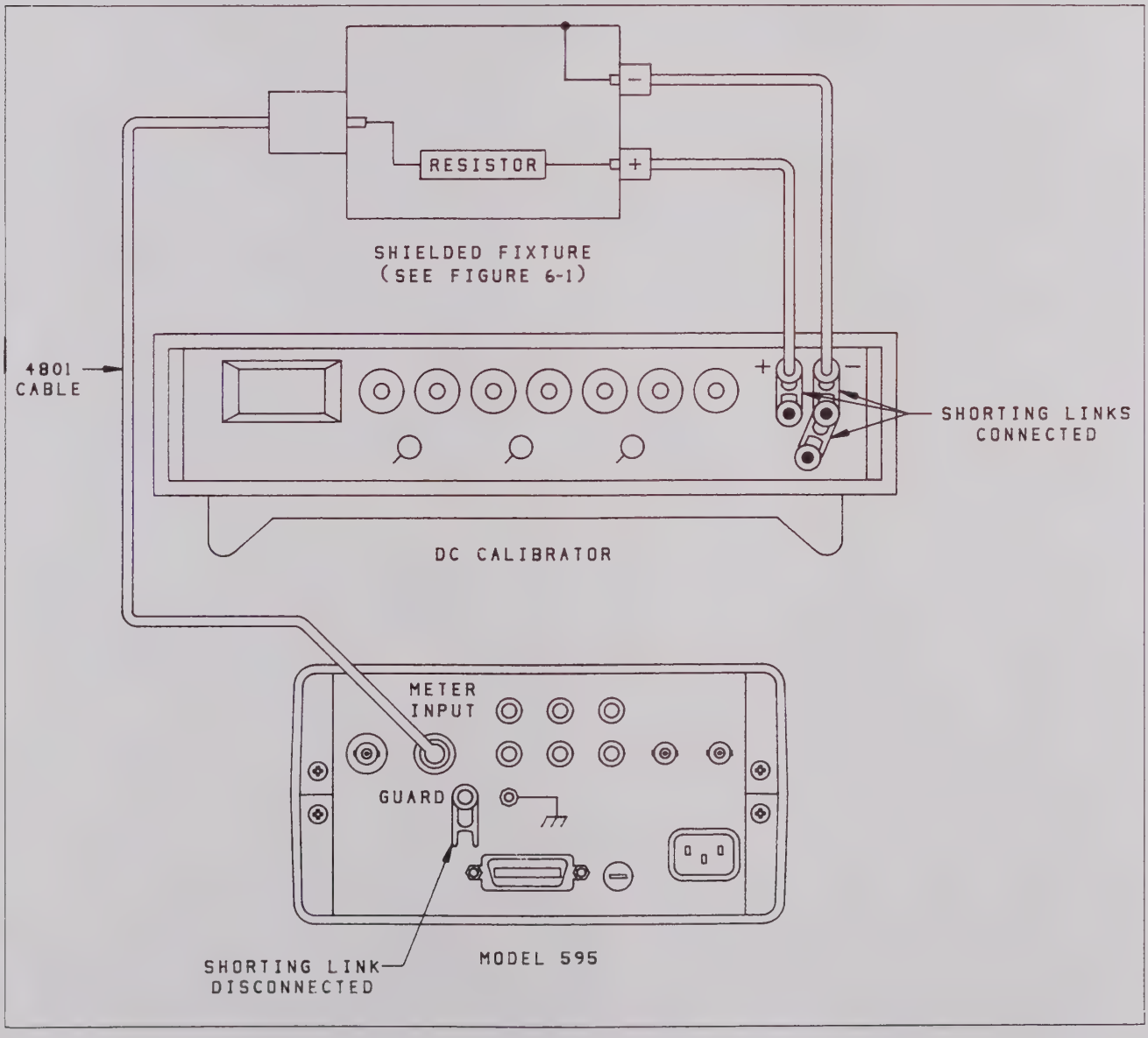


Figure 6-3. Setup for Current Verification (20pA to 20nA Ranges)

6.5.3 Q/t Verification

Perform the following steps to verify Q/t:

1. Place the Model 595 in the capacitance function, 2nF range, set delay time to one second, step voltage to 0,1V squarewave, and then select the Q/t display.
2. With a capped input, verify that the display reads .0000 nA ±2 counts.
3. Using the techniques used to verify the 200pA current range (see previous paragraph), apply 190pA to METER INPUT.
4. Verify that the display reads .1900 nA ±21 counts.
5. Reverse the polarity of the current source and verify that the display reads −.1900 nA ±21 counts.

6.5.4 Capacitance Verification

Capacitance verification consists of connecting capacitors with known measured values to the input and checking that the readings are within allowable limits. The Model 5955 is a set of characterized (measured) capacitors that can be used for verification . Before using the capacitors, make sure that the data for re-characterization has not passed. The characterization procedure for the Model 5955 can be found in its instruction manual.

The capacitance limits used for verification are derived from the accuracy specifictions applied to the actual (not nominal) values of the capacitors. Thus, the capacitance limits must be calculated by the technician. Table 6-3 is provided to simplify these calculations. Perform the following procedure to determine the capacitance limits for the characterized capacitors:

1. Using a pencil, record the reported 1kHz values of the Model 5955 characterized capacitors in Table 6-3 in the column labeled "Reported Capacitance Value". The nominal values of the capacitors are in parenthesis.
2. To determine the allowable readings, complete the table be performing the indicated mathematical operations.
3. Transfer the calculated allowable readings to Table 6-4.

After determing the capacitance limits, the capacitance verification procedure can be performed. Using Table 6-4 as a guide, perform the following procedure to verify capacitance:

1. Place the Model 595 in the following state: Capacitance function, 20nF range, filter 2, 00.10V squarewave step voltage, and 00.20 second delay.
2. Place the supplied cap on the METER INPUT connector.
3. Disable ZERO CHECK (if on) and enable SUPPRESS if thedisplay is not zeroed.
4. Remove the cap and connect the 18nF (nominal) capacitor directly (no cables) to the METER INPUT and VOLTAGE SOURCE OUTPUT connectors of the instrument.
5. Verify that the reading is within the range of readings recorded in the table.
6. Repeat the above basic procedure for the rest of the range entries in Table 6-4. Each table entry defines the instrument setup (RANGE, FILTER, STEP V, delay), input and allowable reading.

Table 6-3. Determining Capacitance Limits

Range	Reported Capacitance Value									Allowable Readings	
										Minimum	Maximum
20nF	(18nF)	_____	×	0.994	=	_____	−	0.002nF	=	_____	
20nF	(18nF)	_____	×	1.006	=	_____	+	0.002nF	=		_____
2nF	(1.8nF)	_____	×	0.992	=	_____	−	0.0002nF	=	_____	
2nF	(1.8nF)	_____	×	1.008	=	_____	+	0.0002nF	=		_____
200pF*	(180pF)	_____	×	0.99	=	_____	−	00.10pF	=	_____	
200pF*	(180pF)	_____	×	1.01	=	_____	+	00.10pF	=		_____
200pF**	(180pF)	_____	×	0.99	=	_____	−	00.20pF	=	_____	
200pF**	(180pF)	_____	×	1.01	=	_____	+	00.20pF	=		_____

*For Step V of 00.10V.
**For Step V of 00.10V.

Table 6-4. Capacitance Verification

Range	Nominal Capacitance Value	Filter	Step V	Delay Time	Allowable Readings* (18° to 28°C)
20nF	18nF	2	00.10 SQ	00.20 S	_____ to _____
2nF	1.8nF	2	00.10 SQ	00.20 S	_____ to _____
2nF	1.8nF	2	00.05 SQ	00.20 S	_____ to _____
2nF	1.8nF	2	00.02 SQ	00.20 S	_____ to _____
2nF	1.8nF	2	00.01 SQ	00.20 S	_____ to _____
200pF	180pF	3	00.10 SQ	00.20 S	_____ to _____
200pF	180pF	3	00.01 SQ	00.20 S	_____ to _____

*Obtained from Table 6-3.

6.5.5 Voltage Source Verification

Use the following procedure to verify that the Model 595 voltage source is within tolerance.

1. Connect the DMM (see Table 6-1) to the VOLTAGE SOURCE OUTPUT connector, as shown in Figure 6-4.
2. Select an appropriate DCV range on the DMM. Alternately, place the DMM in autorange, if desired.
3. Press the DISPLAY SOURCE button to view the voltage source value and turn on its output by selecting the DC waveform.
4. Using the voltage source ADJUST buttons, set the voltage source output to 00.00V.
5. Verify that the voltage source value is within the limits stated in Table 6-5.
6. Repeat steps 4 and 5 above with the remaining voltages listed in Table 6-5.
7. Repeat the procedure for negative voltages of the same amplitude listed in the table.

Table 6-5. Limits for Voltage Source Verification

Programmed Voltage	Allowable DMM Reading (18°C -28°C)
00.00V	– 0.010 to 0.010
00.50V	0.489 to 0.511
01.00V	0.988 to 1.012
05.00V	4.980 to 5.020
10.00V	9.970 to 10.030
15.00V	14.960 to 15.040
20.00V	19.950 to 20.050

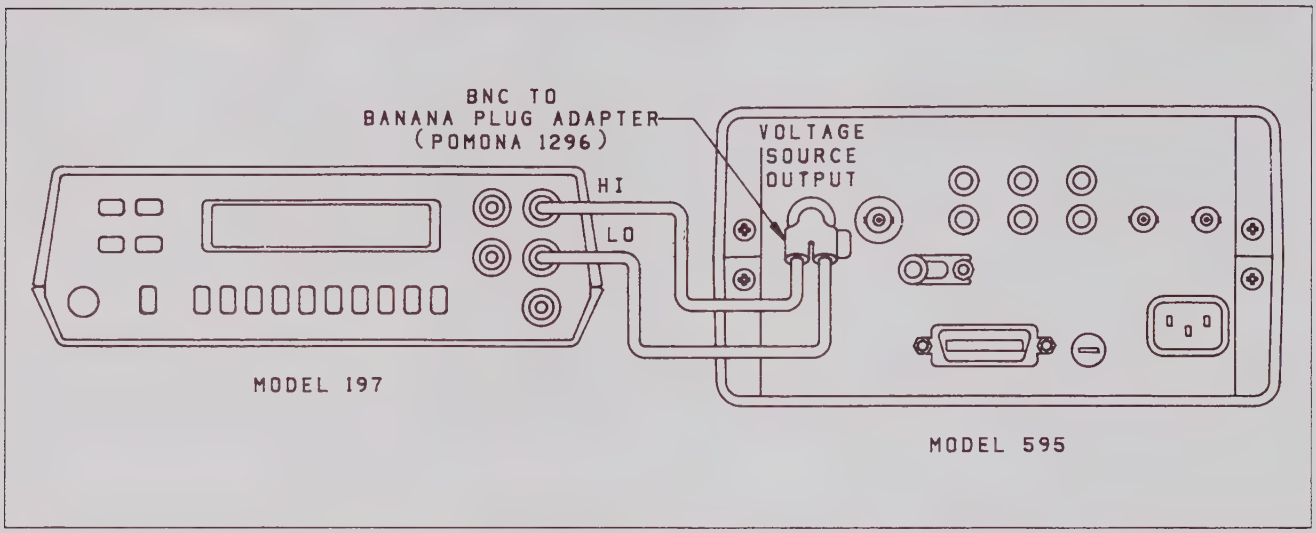


Figure 6-4. Setup for Voltage Source Verification

SECTION 7
THEORY OF OPERATION

7.1 INTRODUCTION

This section contains an overall functional description of the Model 595 in block diagram form as well as details of the various sections of the instrument. Information concerning the voltage source, preamplifier, X10 amplifier, mulitiplexer, −2V reference, A/D converter, digital, analog output and main power supply circuitry is included.

Information is arranged to provide a description of each of the functional blocks within the instrument. Many of these descriptions include simplified schematics and block diagrams. Detailed schematic diagrams and component layout drawings for the various circuit boards are located at the end of Section 9.

7.2 CV MEASUREMENT METHOD

The Model 595 uses the feedback charge method for making CV measurements. As shown in Figure 7-1, one terminal of the capacitance to be measured (C_x) is connected to the voltage source and the other end is connected to the input of the feedback charge amplifier (integrator). Initially, the feedback capacitor (C_f) of the integrator is discharged by closing switch S in parallel with it. When the measurement is ready to begin, S is opened. Any charge transferred to the input of the integrator will now cause a change in the integrator output as follows:

$$\triangle V_{out} = -\triangle Q/C_f$$

The voltage source is then changed by a small amount (dV) causing a charge to to be transferred to Cx. The charge on Cx is proportional to the voltage change (dQ = CxdV). The charge is then applied to the integrator and causes a voltage change at its output. The charge on the feedback capacitor is determined by measuring the integrator output before and after the voltage source step and making the following calculation:

$$\triangle dQ = -C_f \triangle V_{out}$$

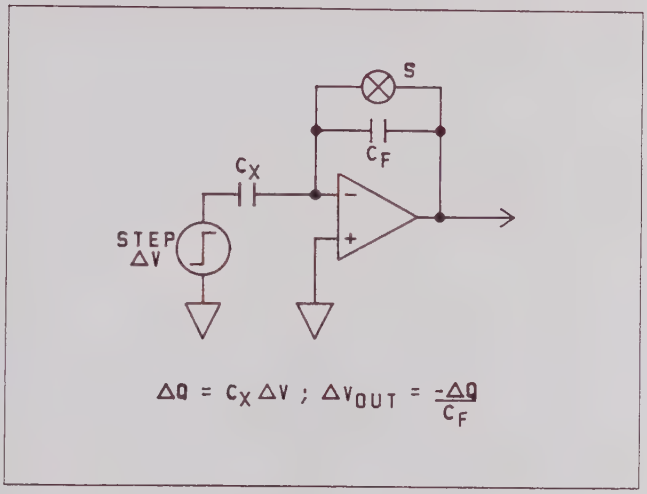


Figure 7-1. Feedback Charge Method

The unknown capacitance (C_x) is then calculated as follows:

$$C_x = \triangle Q/\triangle V = -C_f \triangle V_{out}/\triangle V.$$

Figure 7-2 describes the way in which the charge waveform is measured. The symbols Q1, Q2 and Q3 represent three measurements of charge made at three specific times. Q1 is the baseline charge immediately preceding the voltage step. Q3 is measured after a specified DELAY TIME (t_{DELAY}) and is an indication of the final charge transferred through C_x. Q2 is measured before Q3 (preceding it by t_0) and is used to determine the slope of the charge waveform. This slope indicates the amount of current (Q/t) flowing in C_x during the final portion of the DELAY TIME, t_0. Q/t represents the leakage in C_x or the system. Significant leakage currents can be compensated for with the cCAP (corrected capacitance) feature. With cCAP enabled, the instrument performs the corrected capacitance calculation shown in Figure 7-2.

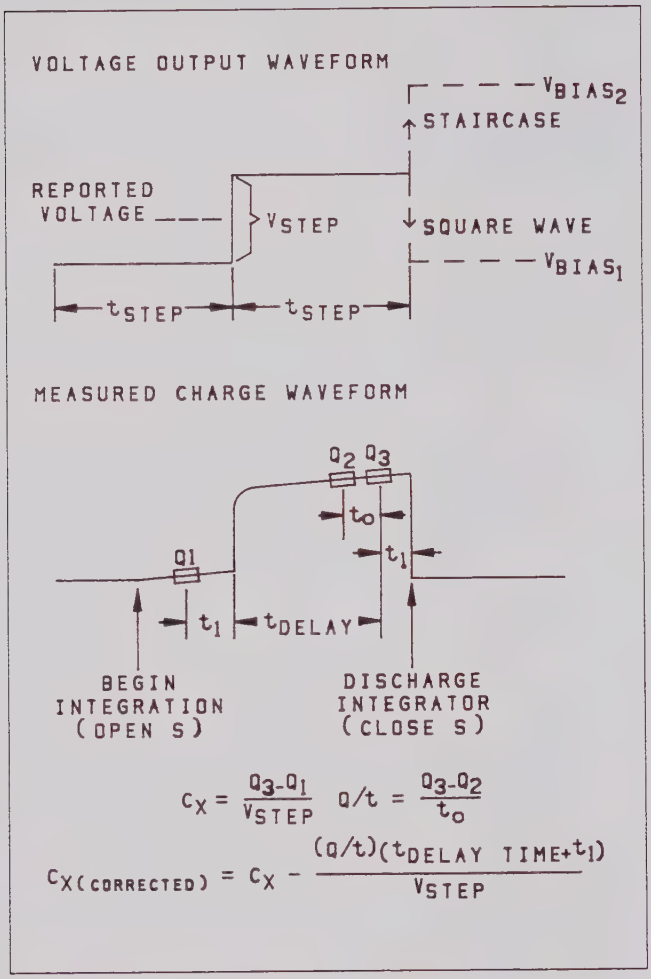


Figure 7-2. Timing Voltage and Charge Waveforms

7.3 OVERALL FUNCTIONAL DESCRIPTION

A simplified circuit diagram of the Model 595 is shown in Figure 7-3. DC voltages and voltage steps are produced by the D/A converter, X2 output stage and precision step source. Current or charge is converted to voltage and then to a digital signal by the preamplifier, X10 amplifier and A/D converter. Both the A/D and D/A converters communicate with the microprocessor via optocouplers in order to provide isolation of analog signals from digital interference. The analog section and digital section may by independently floated with respect to chassis ground by ±30V.

The digital section is based upon the 146805E2 CMOS microprocessor. It performs the tasks of controlling the configuration of the preamplifier and A/D converter, programming the D/A converter and step source, receiving and interpreting measurements from the A/D converter, displaying data, communicating over the IEEE-488 bus, and programming the analog outputs.

7.4 VOLTAGE SOURCE

In order to provide device bias and precision steps for the feedback charge method, the Model 595 has a ±20V 2mA voltage source. The source is based upon an AD7543 12-bit serial input monolithic D/A converter (U139). A multiplexer (U130) is used to select one of four precision steps or zero which is then summed with the D/A converter output (scaled X2) in the output stage.

7.4.1 D/A Converter

The D/A converter and associated circuitry are shown in Figure 7-4. U139 is a multiplying current output converter. A 12-bit digital value is programmed serially through the SRI, STB1, and LD2' inputs. This digital value determines what proportion of the output current is switched to Iout1 and what is switched to Iout2. The sum of Iout1 and Iout2 is always Vref/Rf. The reference is generated with U134 by amplifying the 6.3V zener voltage of VR101 to 10.24V, according to the ratio of R118 and R166 to R120. Q108 buffers the output of U134 for higher output current. VR101 bias current is set at 1.9mA (nominal) by R127 (0.2mA is drawn by other circuitry).

Op-amp U140B is used to convert Iout1 to a voltage, with the internal Rf of U139 as its feedback resistor. The specified value of Rf is 5k to 25kΩ and it is TC (temperature compensated) matched to the D/A's R-2R ladder. With U140B alone, the D/A output would be unipolar, from 0V to −10.2375V. However, U140A, R143 and R140 are used to invert Iout2 which is then summed with Iout 1 at the summing node of U140B. This causes the output swing to be bipolar from −10.235 to +10.24V. One LSB would correspond to 5mV (X2 gain will make this 10mV at the output of the instrument). R129, R132 and R148 are used to reduce the offset voltage by ½ LSB to compensate for an offset which results from the bipolar configuration.

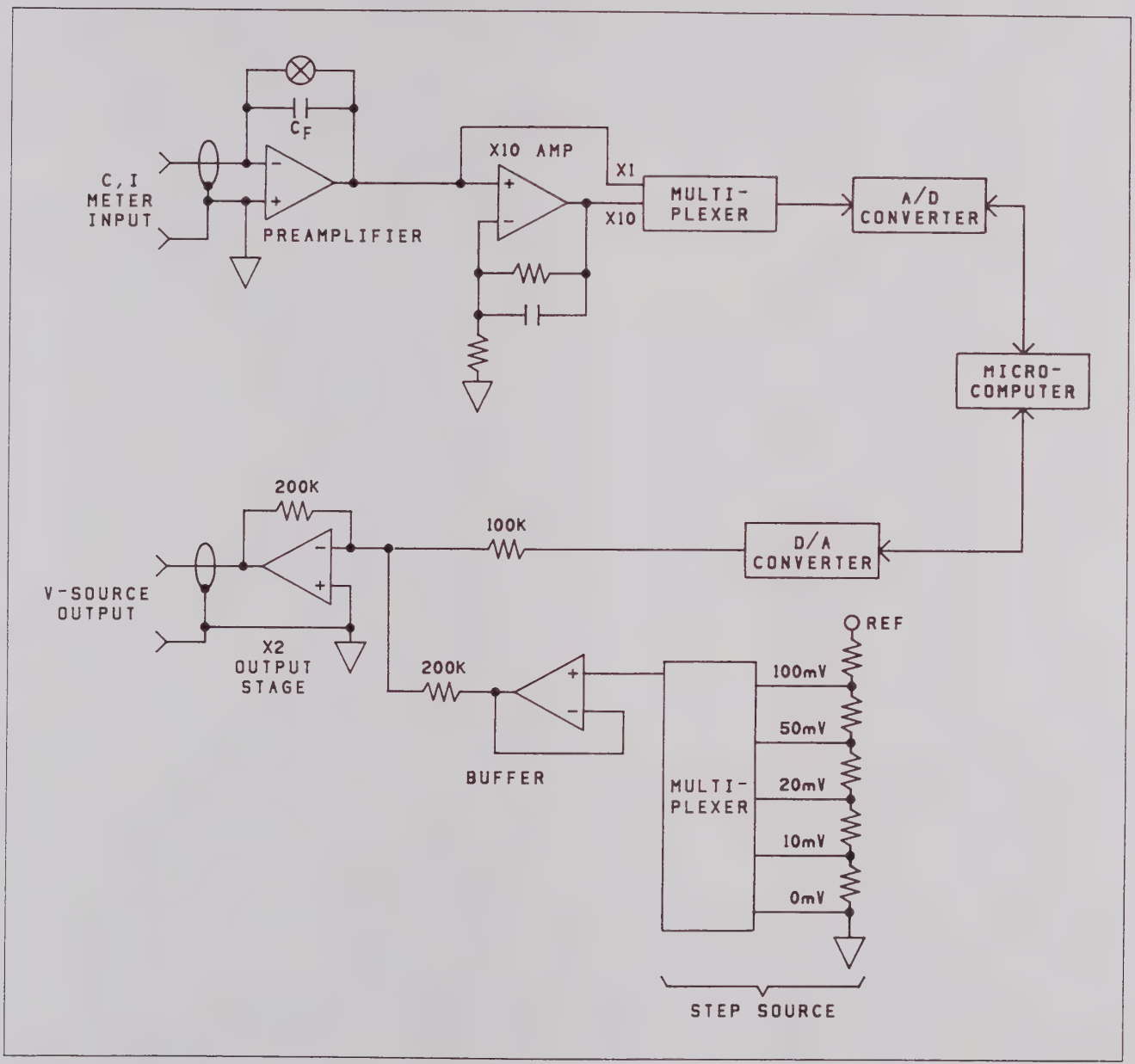


Figure 7-3. Model 595 Simplified Diagram

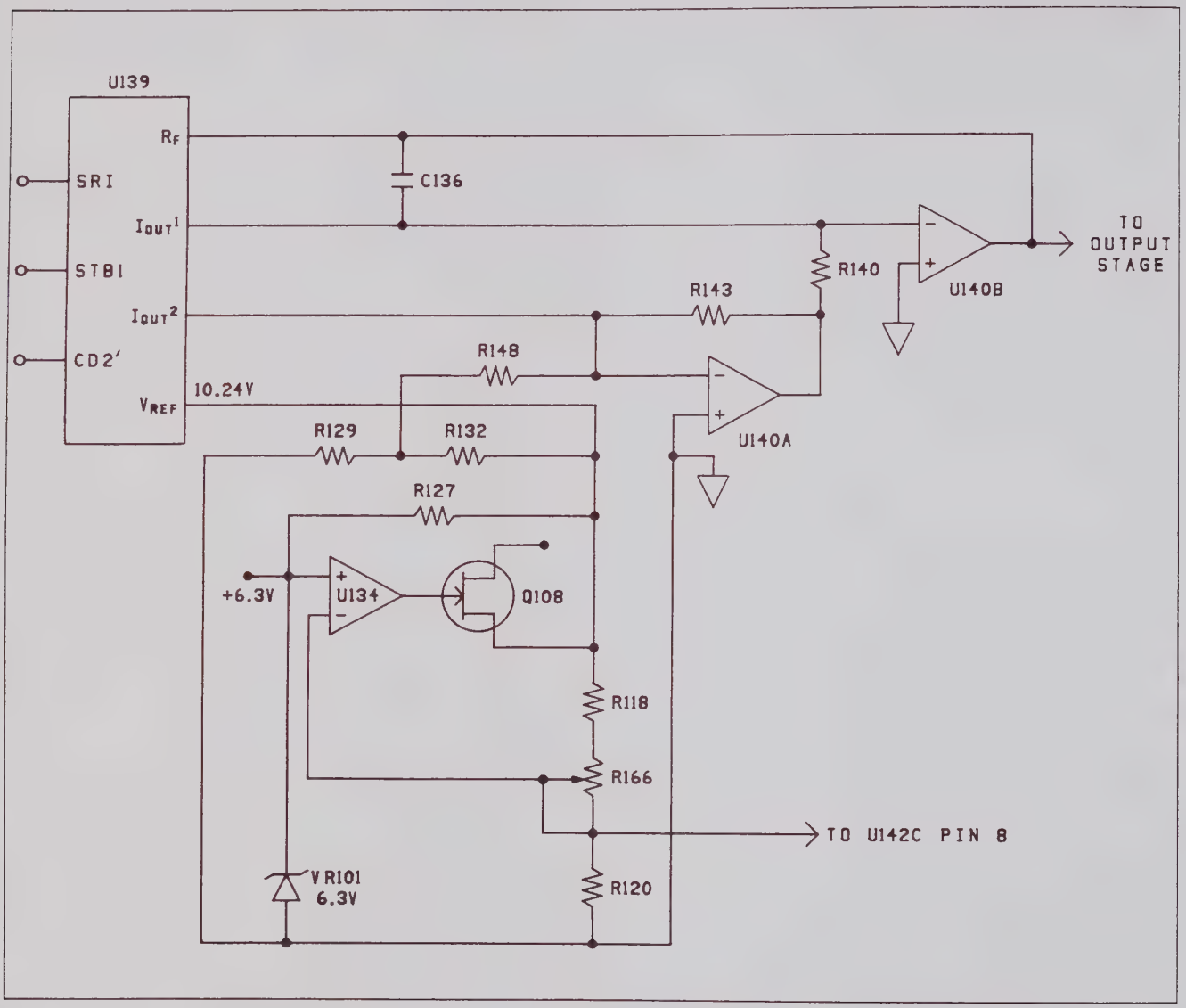


Figure 7-4. Voltage Source D/A Converter Circuitry

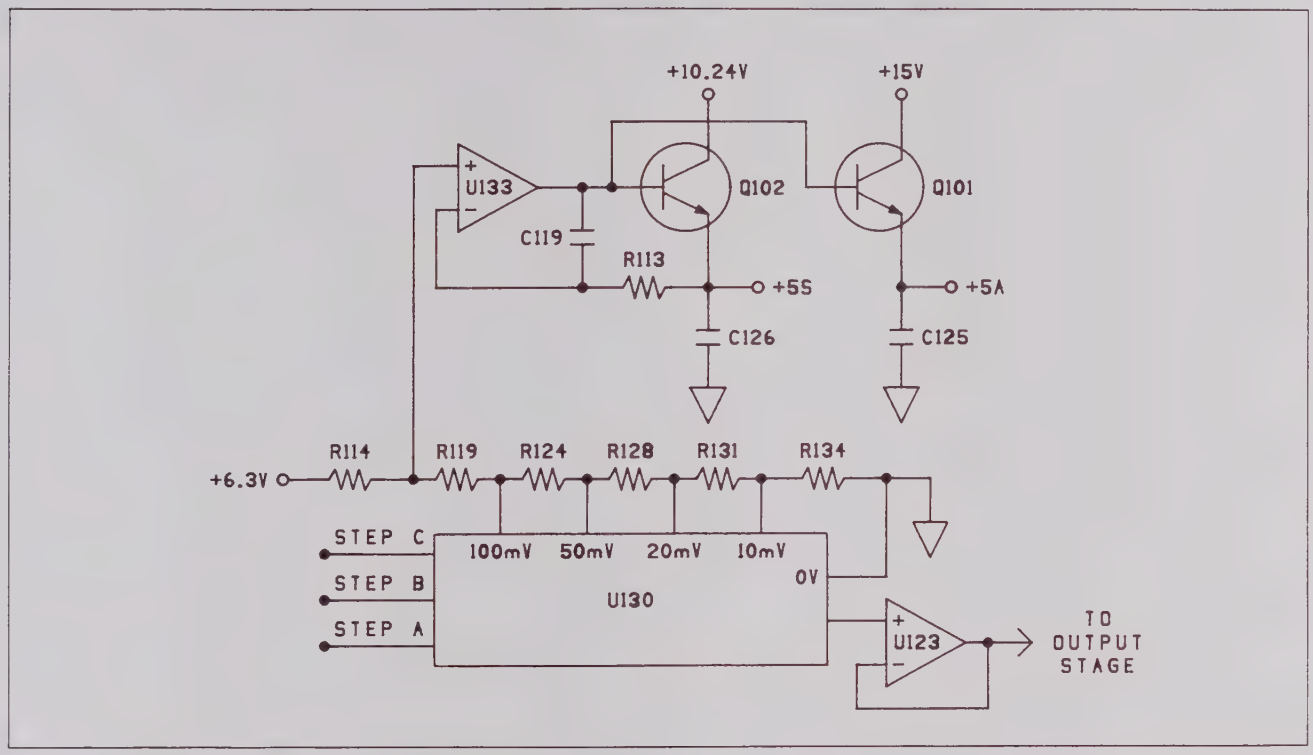


Figure 7-5. Precision Step Source

7.4.2 Precision Step Source

In making a capacitance measurement, the Model 595 will measure charge and divide it by the value of a step in voltage across the capacitor being tested. The step source circuit is shown in Figure 7-5. The resistor divider formed by R114, R119, R124, R128, R131 and R134 divides the 6.3V reference down to 5V, 0.1V, 0.05V, 0.02V and 0.01V. The 5V level is used by U133 and associated components to produce +5A and +5S supplies from +15V. The remaining four levels are multiplexed by U130 to the input of U123 according to the inputs STEP A, B and C. U123 is just a low noise and drift buffer so its output represents any one of the four precision low level voltages or ground.

7.4.3 Output Stage

The outputs of the precision step source and the D/A converter are combined, buffered, and current limited by the output stage of the voltage source. A simplified diagram of the output stage (minus the current limiting circuitry) is shown in Figure 7-6. The output stage is basically an inverting amplifier. The compound op-amp is composed of U141, Q113, Q114, and various resistors and capacitors for biasing and frequency compensation. Feedback is provided by R167 and C140. Inputs to the inverting amplifier are made by R138 and R152 from the step source and D/A converter respectively. Gain is −X1 for the step source and −X2 for the D/A converter.

RFI emissions and susceptibility of the source are reduced with common mode choke T103 and bypass capacitors C143 and C146.

The current output of the voltage source is limited to 4mA maximum. Figure 7-7 shows the additional circuitry of the output stage that provides current limiting. Current limiting occurs at 3mA ±1mA. In the positive half of the complementary output stage, Q103 turns on when a positive current limit occurs. The base current to Q113 is shunted away preventing the output capability of the stage from rising any higher. CR114 is kept reverse biased during normal operation keeping the open-collector output of U142B off. During current limit, CR114 is forward biased when Q103 turns on. This is sensed by U142B whose output pulls down, switching Q107 on and turning on U122. The microprocessor can then detect a current limit condition in the voltage source via optocoupler U122. For the negative half of the complemenary stage, Q104, CR115, U142A and R141 perform similar functions.

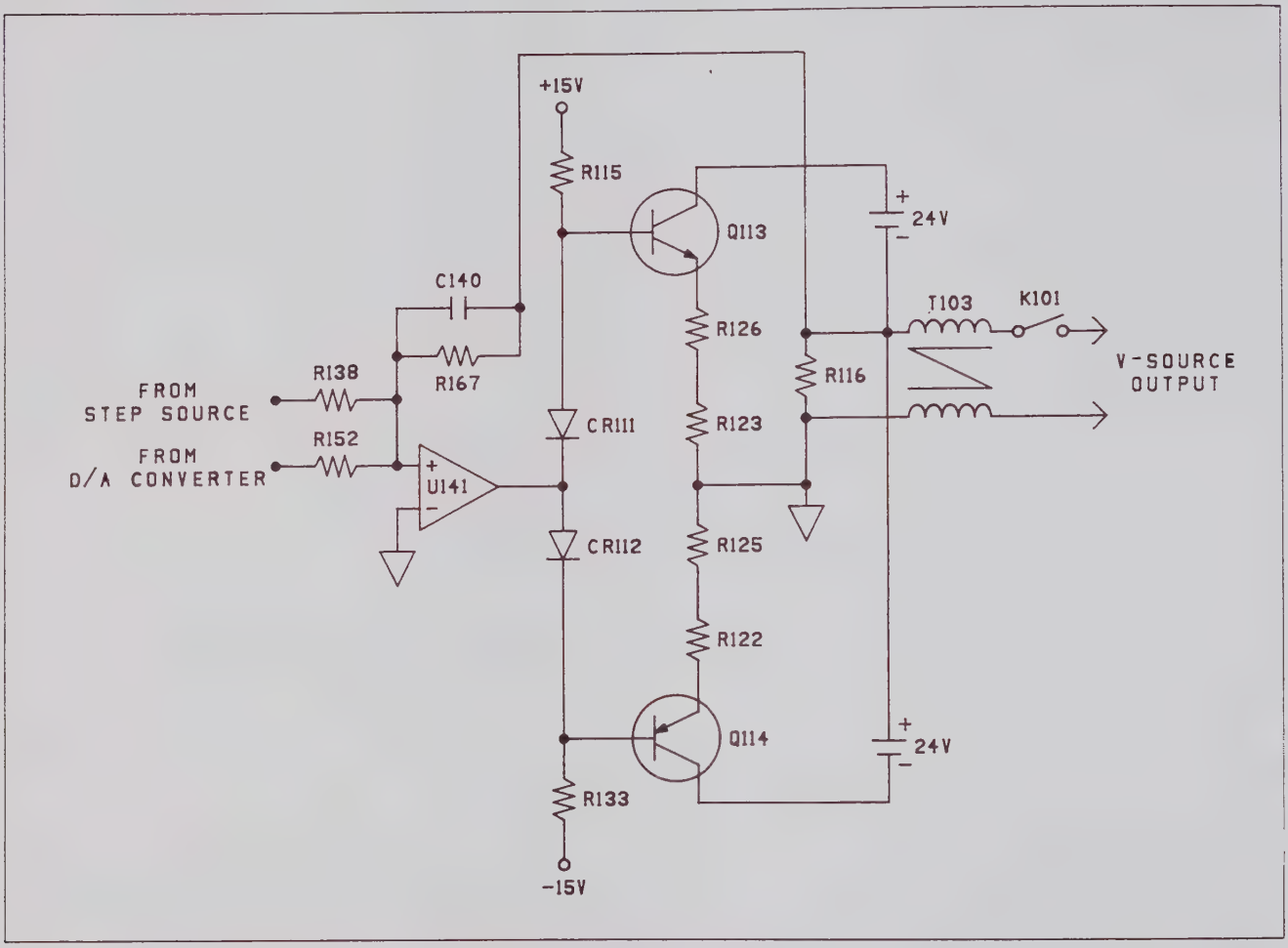


Figure 7-6. Output Stage Circuitry (Simplified)

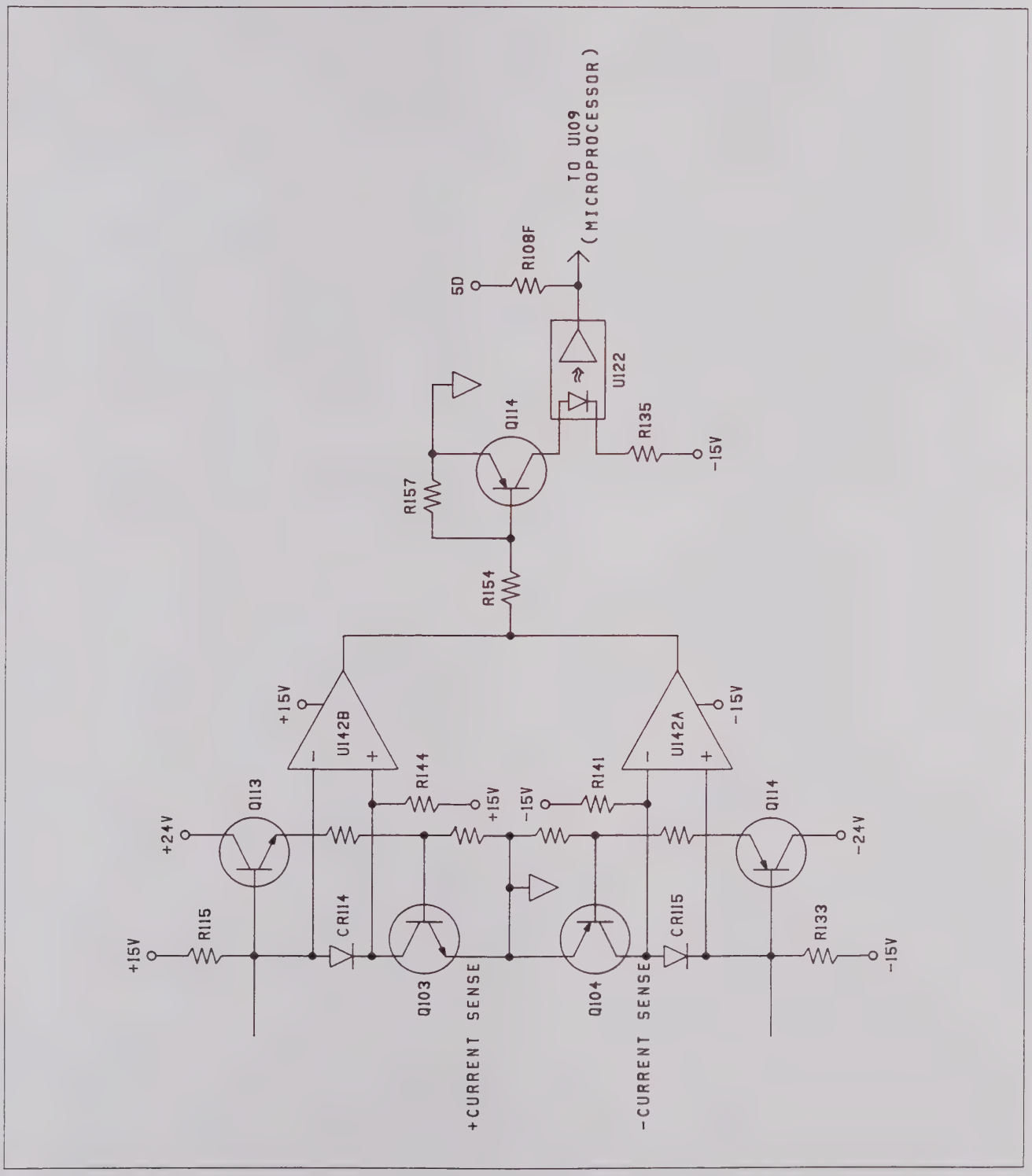


Figure 7-7. Current Limiting for Output Stage

7.4.4 Reset Circuit

Since sensitive devices are likely to be connected to the output of the voltage source and may not be removed before power is turned off, it is desirable to have the source reset (disconnect) when power is removed. This is advisable because the output of the source is determined by digital signals which may be erroneous during power down before the analog supplies decay to zero. The reset circuitry is shown in Figure 7-8. A half-wave rectifier is formed by CR117, R163, R165 and C138. C138 is charged through R163 and then partially discharged through R163 and R165 as the AC voltage cycles. The result is an average of around 12V across C138. This level is compared to the +6.3V of the D/A reference circuit by U142C. When power is turned on, this will by sensed within two line cycles, releasing the open collector output of U142C. The gate of Q115 will then be raised by R139, R162 and C142 to its threshold in 1.5s, turning on K101 and connecting the output of the source to the BNC connector (see Figure 7-6). On power down, C138 is discharged in 10ms to 26ms to below 6.3V. Thus, the output of U142C pulls down, turning off Q115 abruptly. This opens K101, disconnecting the output of the source from the BNC connector.

7.5 PREAMPLIFIER

The preamplifier of the Model 595 converts the input signal (current or charge) to a 0.2V or 2V full range voltage. Because of the very low levels of current and charge to which the instrument is sensitive, the preamplifier is required to have an input bias current of <5fA. Figure 7-9 shows a block diagram of the preamplifier. The input stage (Q302) and op-amp (U305) form a compound amplifier satisfying the input requirements. Feedback is applied around this compound op-amp to set the proper transfer function of the preamplifier.

7.5.1 Preamplifier Configurations

Specific configurations of the preamplifier for current and capacitance measurements are shown in Figure 7-10. The Model 595 measures full range current levels from 20pA to 200μA using 10k, 998k, 100M and 10GΩ feedback resistors. For capacitance, full range meausurements are from 200pF to 20nF using feedback capacitors of 10pF, 100pF and 1nF.

Before each capacitance measurement, the feedback charge amplifier is discharged by a low-leakage bridge switch (signified by S) which is described in more detail in paragraph 7.5.

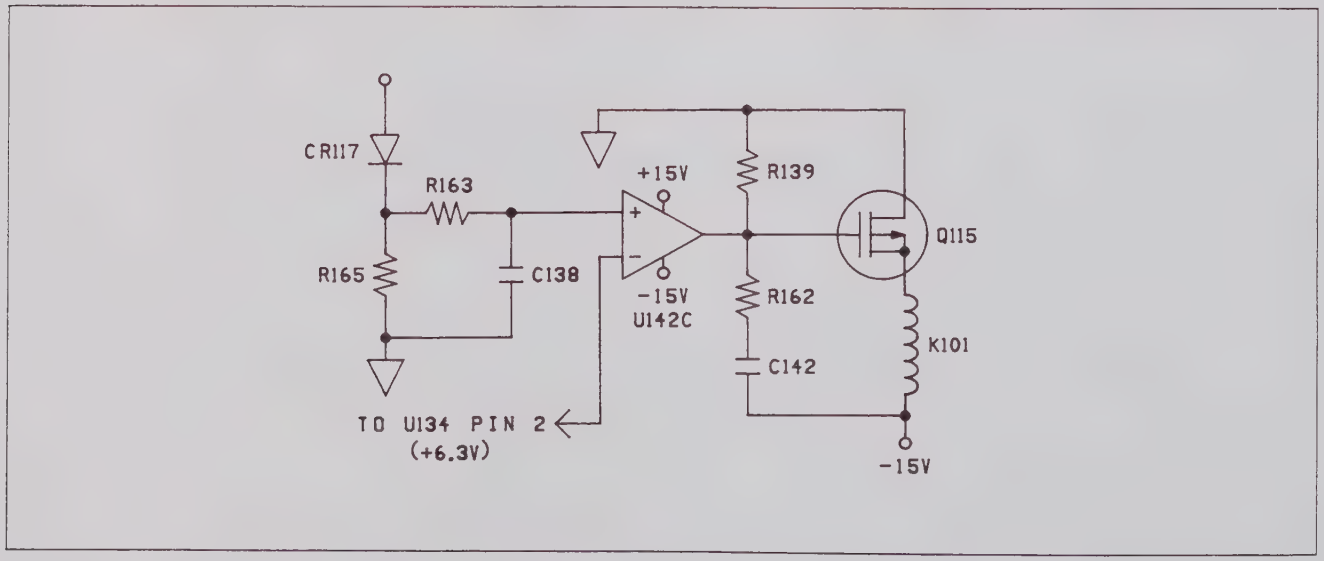


Figure 7-8. Voltage Source Reset Circuitry

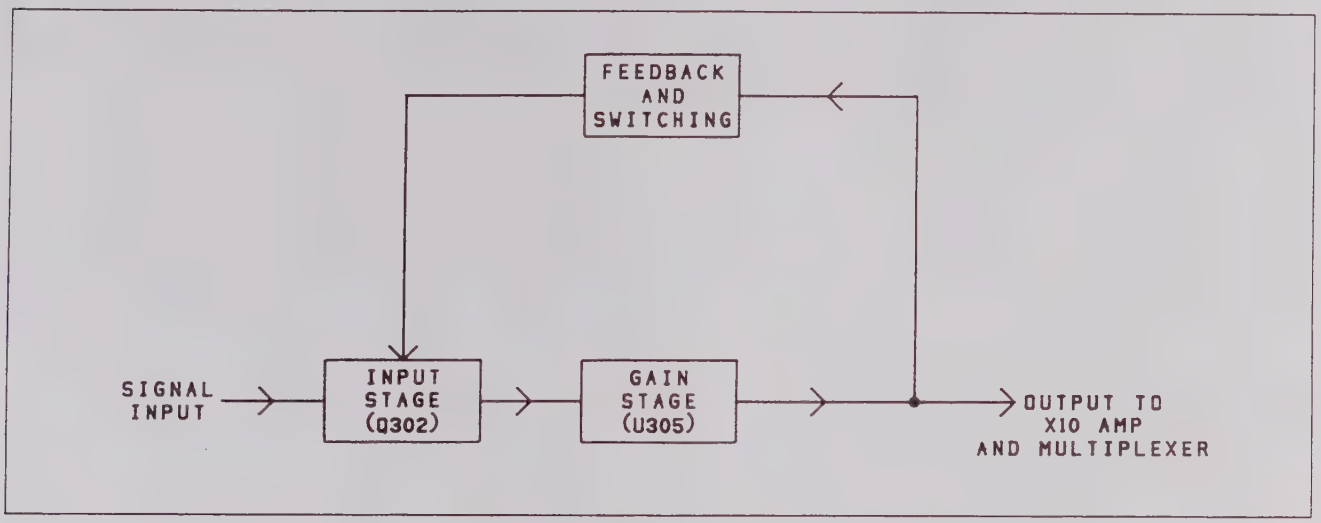


Figure 7-9. Block Diagram of Input Preamplifier

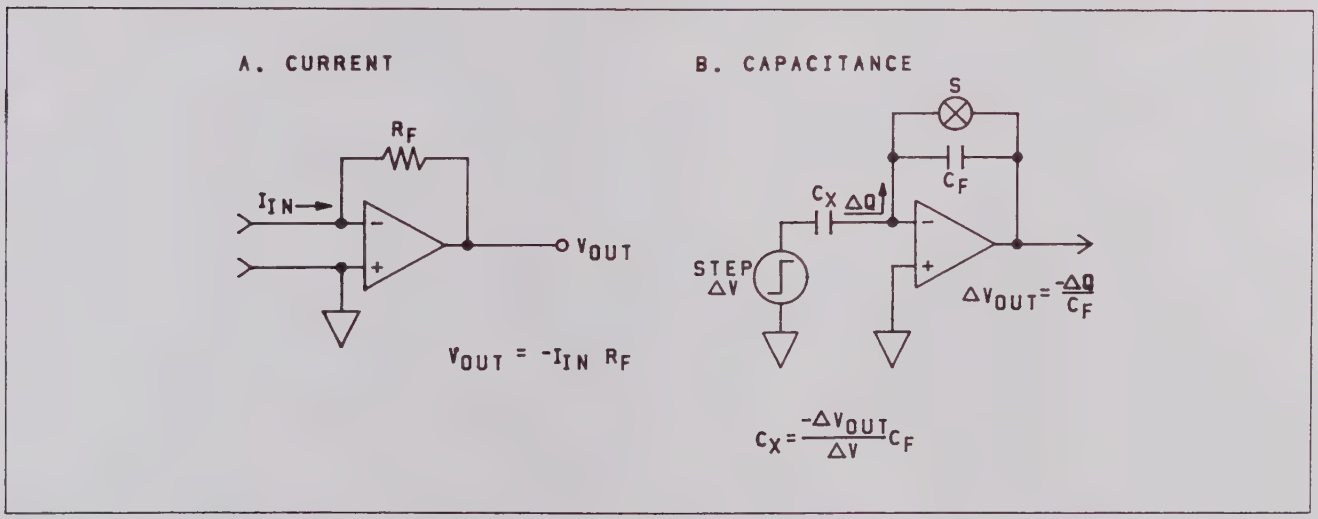


Figure 7-10. Circuit Configuration for Current and Capacitance

7.5.2 Input and Gain Stages

The preamplifier input stage and gain stage (U305) is shown in Figure 7-11. The input stage consists of a propriatary JFET amplifier circuit, offset voltage circuit and input bias current compensation. The gain stage simply consists of a single IC operational amplifier (U305).

The JFET amplifier circuit is comprised of Q302, R323, R324, R312, R313 and R314. This biasing configuration results in lower input bias current (gate current).

To compensate for the offset voltage of this stage, the non-inverting gate of Q302 is connected to the divider formed by R320, R319, R315, R318 and W301. Depending on the position of jumper W301 and potentiometer R315, the voltage at the gate of Q302 will be from −20mV to +20mV, directly offsetting the voltage error which would otherwise appear at the input-side gate of Q302.

Input bias compenation is provided to optimize the input bias current of the instrument. The components involved are R317, RT301, R322, RT302, R321 and R316. The wiper of R317 is adjustable to ±5V. This voltage is divided with RT301 and R322 by 20 and again by 50 with RT302 and R321. RT301 and RT302 are thermistors whose combined temperature dependence tracks the JFET leakage. The voltage applied to R316 is then nominally ±5mV, but changing with temperature. Since R316 is 250GΩ and it is connected to the virtual ground input of the amplifier at its other terminal, ±20fA compensation at 23°C is possible.

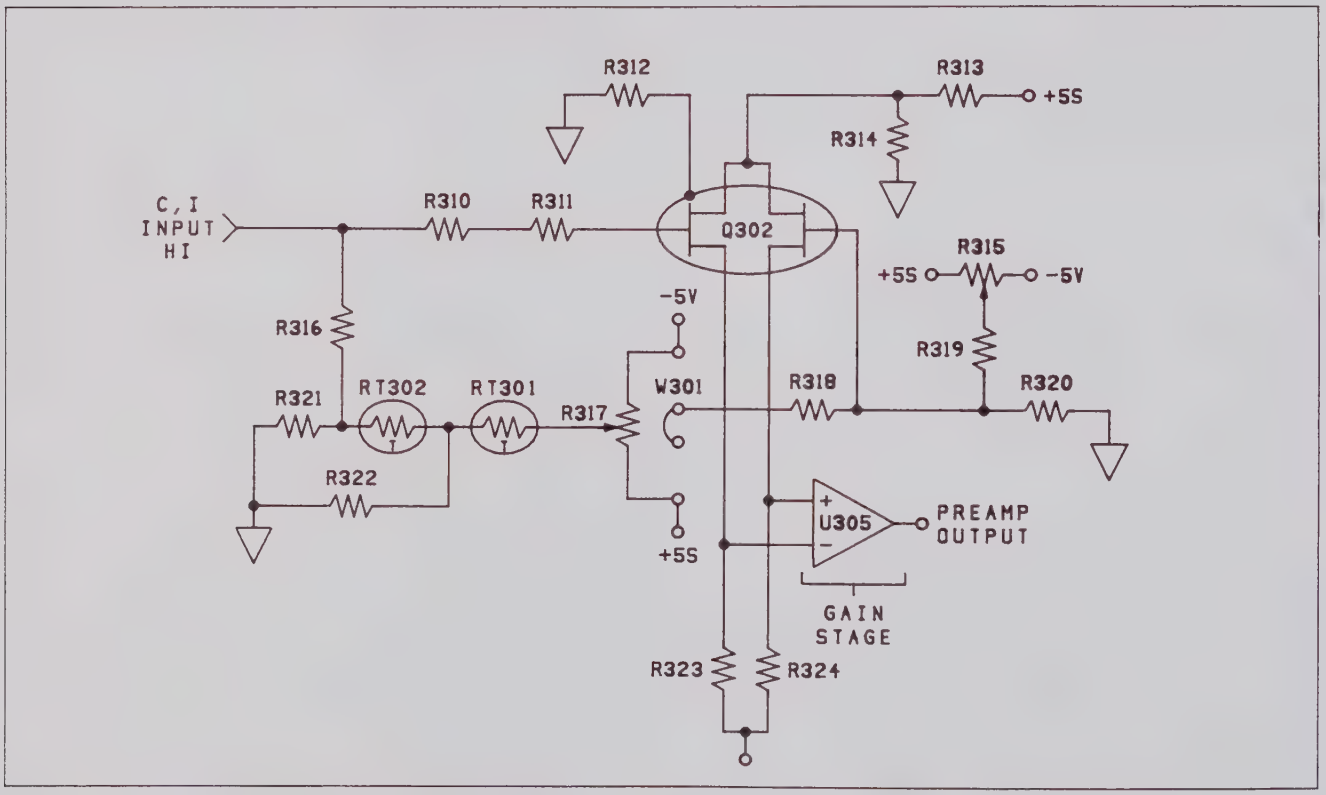


Figure 7-11. Input Stage and Gain Stage

7.5.3 Feedback Elements

Various resistors and capacitors are switched in as feedback around the compound op-amp to configure the preamplifier for specific ranges of the current and capacitance functions. The configuration of the feedback elements and relay switches are shown in Figure 7-12. Table 7-1 shows the state of the relay switches for each range. C322 and C302 are unswitched feedback capacitors which combine to be the 10pF feedback element. K305 and K303 switch the 91pF (C303) and 1000pF (C304) capacitors respectively for the other capacitance ranges.

Range switching for the current function is accomplished with relays K302, K304, K306 and K307. Capacitors are connected in parallel with the feedback resistors to avoid stability problems when shunt capacitance is high and to set the response time constant and bandwidth.

The ZERO CHECK relay (K301) is also configured as a feedback element, isolating the preamplifier from the input by 10MΩ.

Table 7-1. Relay Switch Configuration

Function	Range	Relay						
		K301	K302	K303	K304	K305	K306	K307
Capacitance	200pF							
	2nF					X		
	20nF			X				
Current	20pA						X	
	200pA						X	
	2nA				X	X		
	20nA				X	X		
	200nA		X	X				
	2 μ		X	X				
	20 μ			X				X
	200 μA			X				X
	Zero Check	X	*	*	*	*	*	*

X = Relay Switch Closed

* = These relay switches may also be closed depending on range and function.

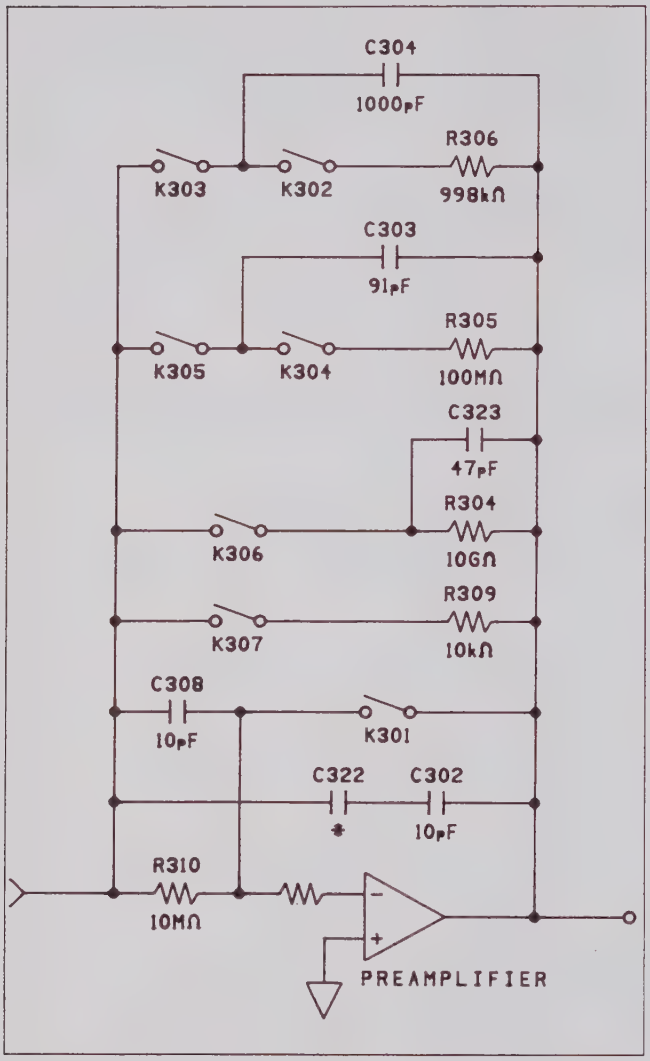


Figure 7-12. Feedback Element

7.5.4 Fast Discharge Bridge

During capacitance measurements, the preamplifier of the Model 595 acts as a charge amplifier, integrating all charge which flows into the instrument input. Because the preamplifier output will eventually saturate at the supply rail, it is necessary to periodically discharge the preamplifier and begin integrating again from a known, low value of charge. In order to maximize dynamic range of the measurement (resolution compared to maximum reading), the preamplifier is discharged before every capacitance reading. To minimize the effects of charge injection (charge hop), the baseline charge is measured following discharge and subsequent charge measurements are referrenced to this baseline.

The discharge switch is a low leakage diode bridge (Q304 and Q305) as shown in Figure 7-13. The switch is biased on by passing a current of 20uA through it. This turns all four diodes on. Bias current to the top of the bridge is provided through R351 when the discharge line (U302 pin 11) goes to 5V. This 5V signal is inverted to −5V by R353, U314 and R352. The bias current from the bottom of the bridge thus flows through R350 when discharge causes the output of U314 to go to −5V.

The level of charge injection during switching is high enough with this switch to require compensation. This is provided by R347, R303, R346 and C320. The resistors form and adjustable divider with a ±250mV output step that coincides with the switch transition. Through C320, this corresponds to a ±5pC charge injection compensation range.

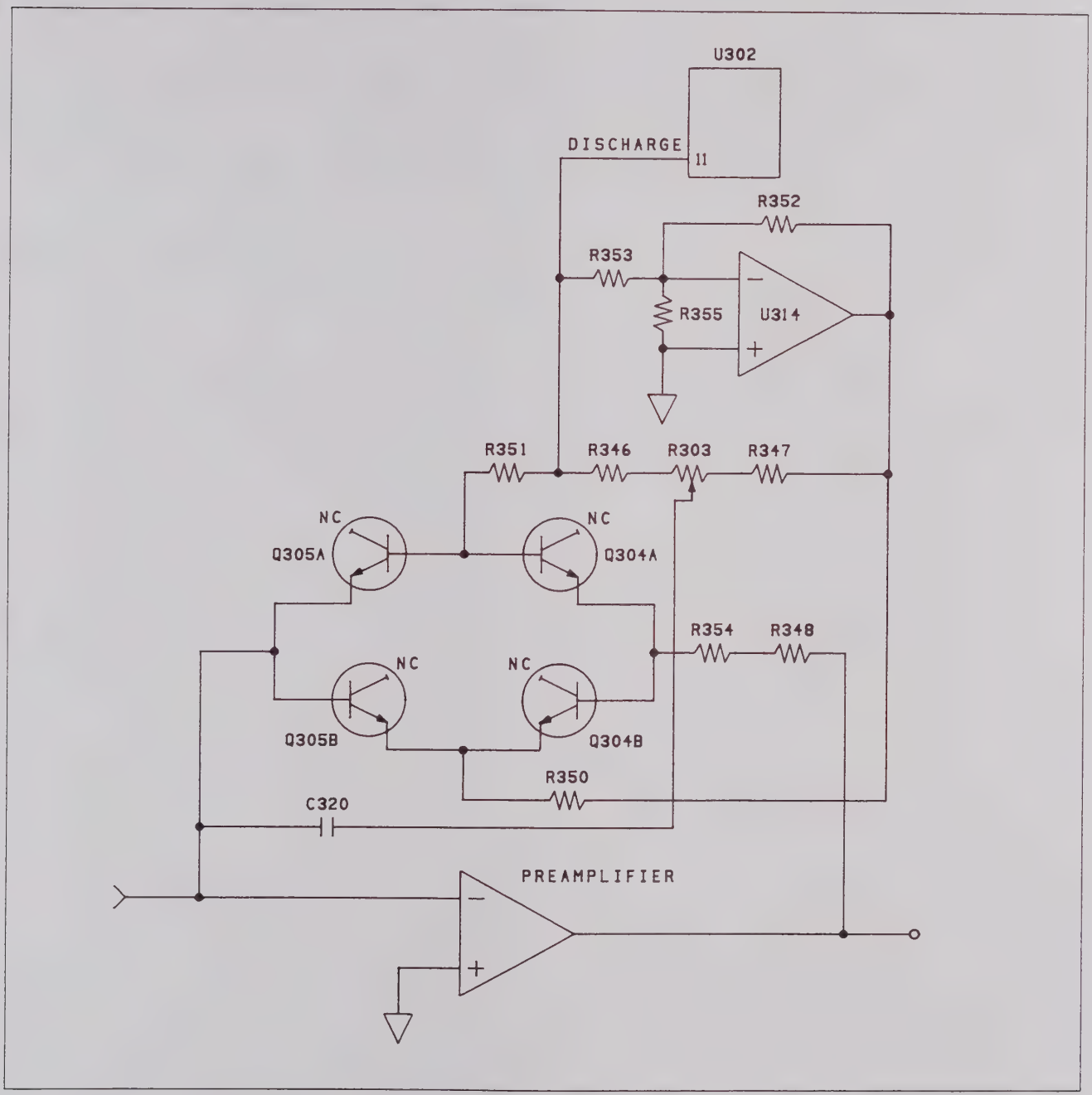


Figure 7-13. Fast Discharge Circuitry

7.6 X10 AMPLIFIER

Ranging is accomplished through not only the feedback elements of the preamplifier, but the X10 amplifier shown in Figure 7-14 as well. This circuit is used to amplify the ±0.2V output of some ranges to the ±2.0V signal level required by the A/D converter. The X10 amplifier is comprised of U304, R307, R308 and C307. C305 and C306 are offset null storage capacitors for U304. The configuration is simply a non-inverting X10 gain with the time constant set by C307 to be 218μsec.

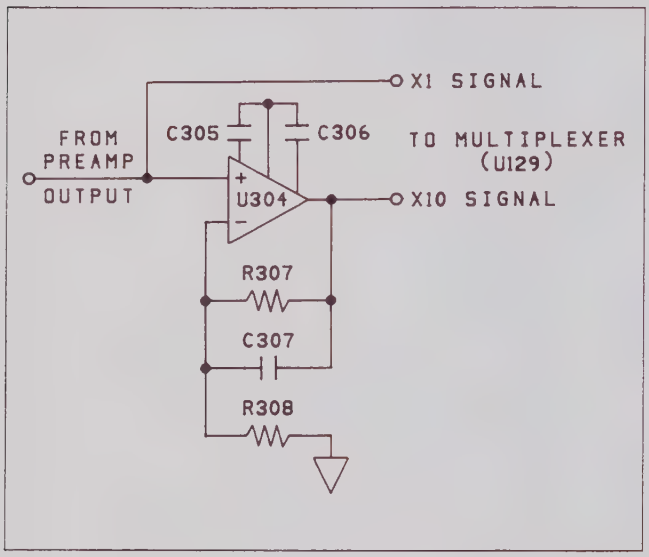


Figure 7-14. X10 Amplifier Circuitry

7.7 MULTIPLEXER and BUFFER AMPLIFIER

The multiplexer selects among the three signals that are part of the Model 595 measurement cycle. During the common phase, the multiplexer selects the signal common. During the reference phase, the −2V reference voltage is selected, while the signal from the preamplifier (X1) or the X10 amplifier is selected during the signal phase.

Figure 7-15 shows a simplified schematic of the multiplexer and buffer amplifier. U129 is the multiplex IC, which contains CMOS devices that act as analog switches to select among the three input signals.

Figure 7-16 shows the general signal switching phases for the three signals. During each phase, an integration is performed by the A/D converter, and the resulting data is then used by the microprocessor to calculate the final reading.

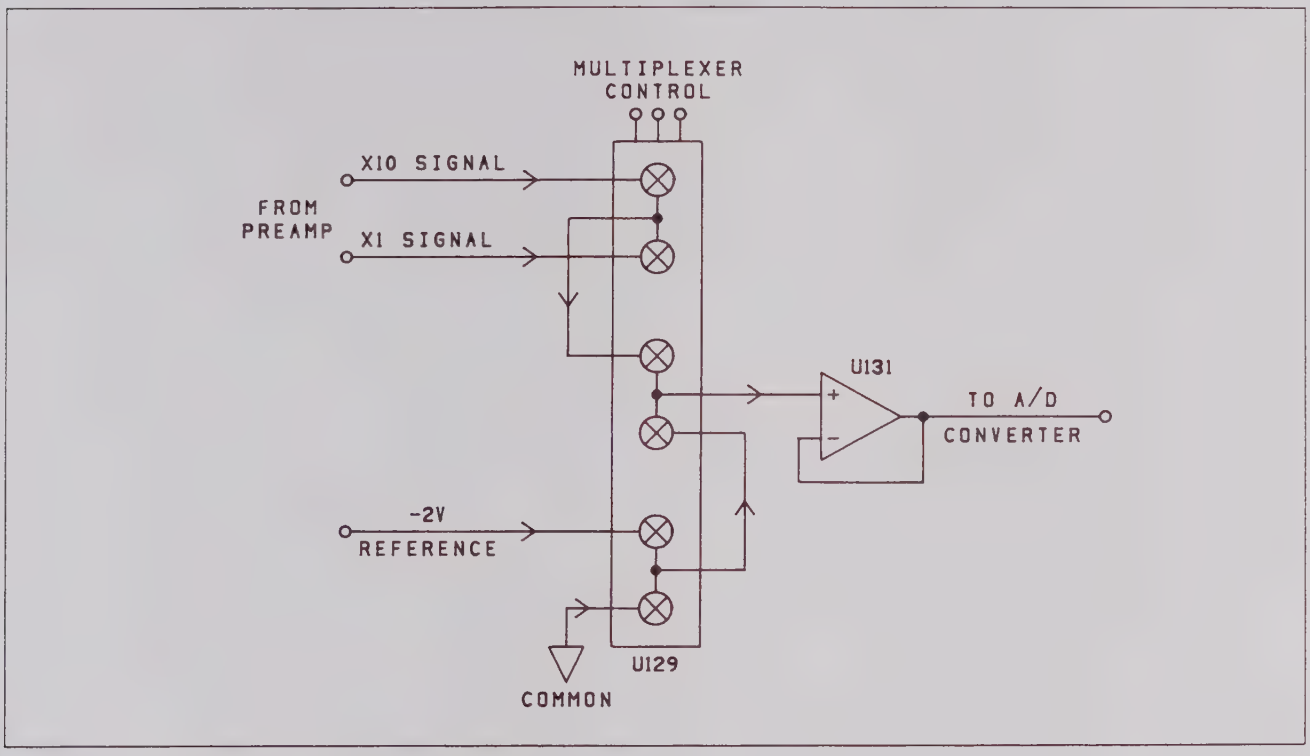


Figure 7-15. Multiplexer and Buffer

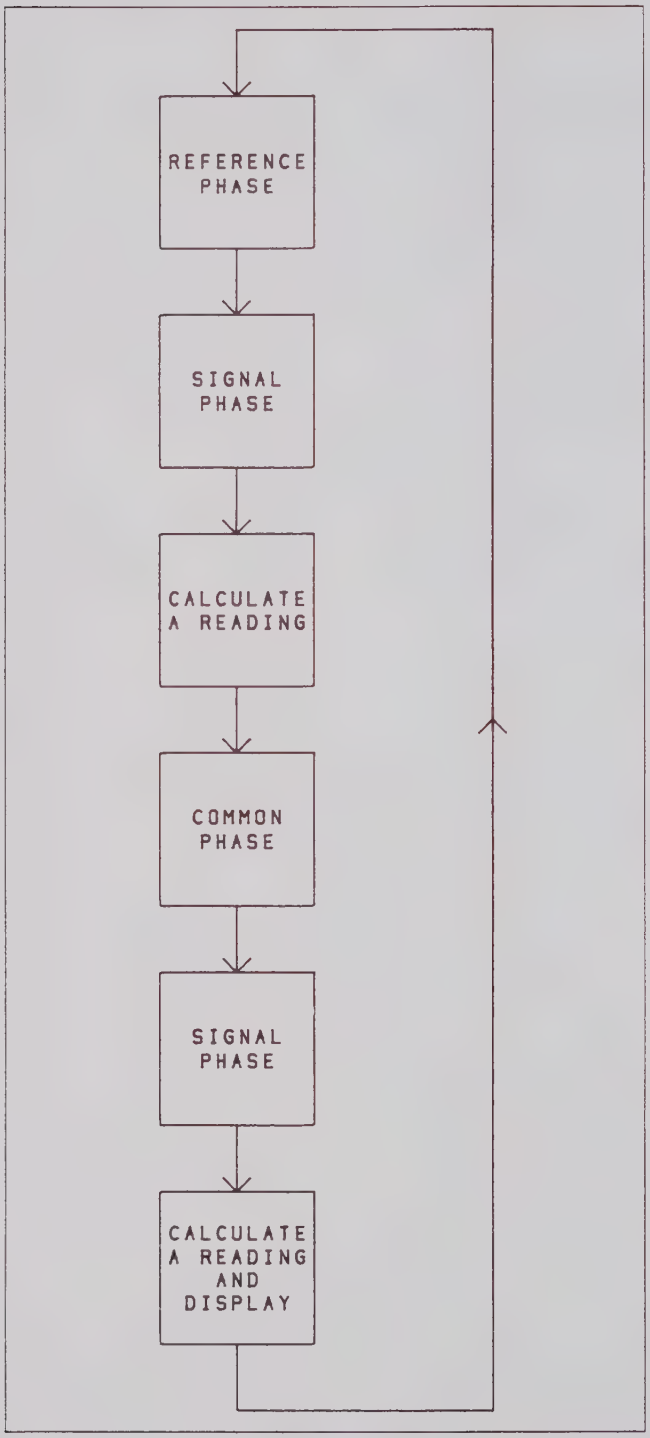


Figure 7-16. Multiplexer Phases

7.8 −2V REFERENCE SOURCE

Measurements are based on comparing the unknown signal with an internal −2V reference voltage source. During each measurement cycle, the unknown signal is sampled and then compared with the signal common and the −2V reference values. Figure 7-17 shows a simplified diagram of the −2V reference source. VR102 provides a highly stable −6.3V reference, while U138, Q106, R145, R147 and R151 provide a constant current to minimize zener voltage variation. R156A and B divide the down the −6.3V value to the final −2V reference voltage.

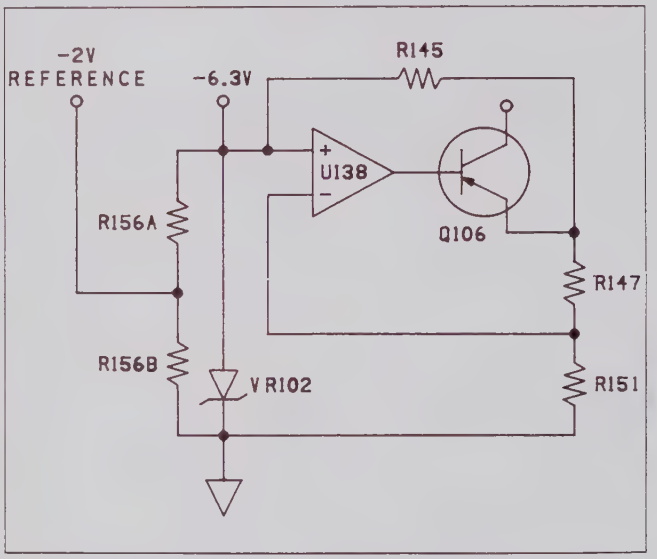


Figure 7-17. −2V Reference Source

7.9 A/D CONVERTER

The Model 595 uses an A/D converter that utilizes both constant-frequency charge balance and single-slope techniques. This combination gives the instrument both high accuracy and relatively fast conversion times.

A simplified schematic of the A/D coverter is shown in Figure 7-18, along with an associated integrator waveform.

The charge balance phase begins when the input ENABLE/DISABLE line is set high. This action occurs at the end of a software generated delay period that allows the signal to settle following signal selection. Once the input is enabled, the signal from the buffer amplifier is added to the level shift current applied through R161 and coupled tothe integrator. In this manner, the ±2V bipolar signal from the buffer amplifier is converted to a unipolar signal that can be integrated.

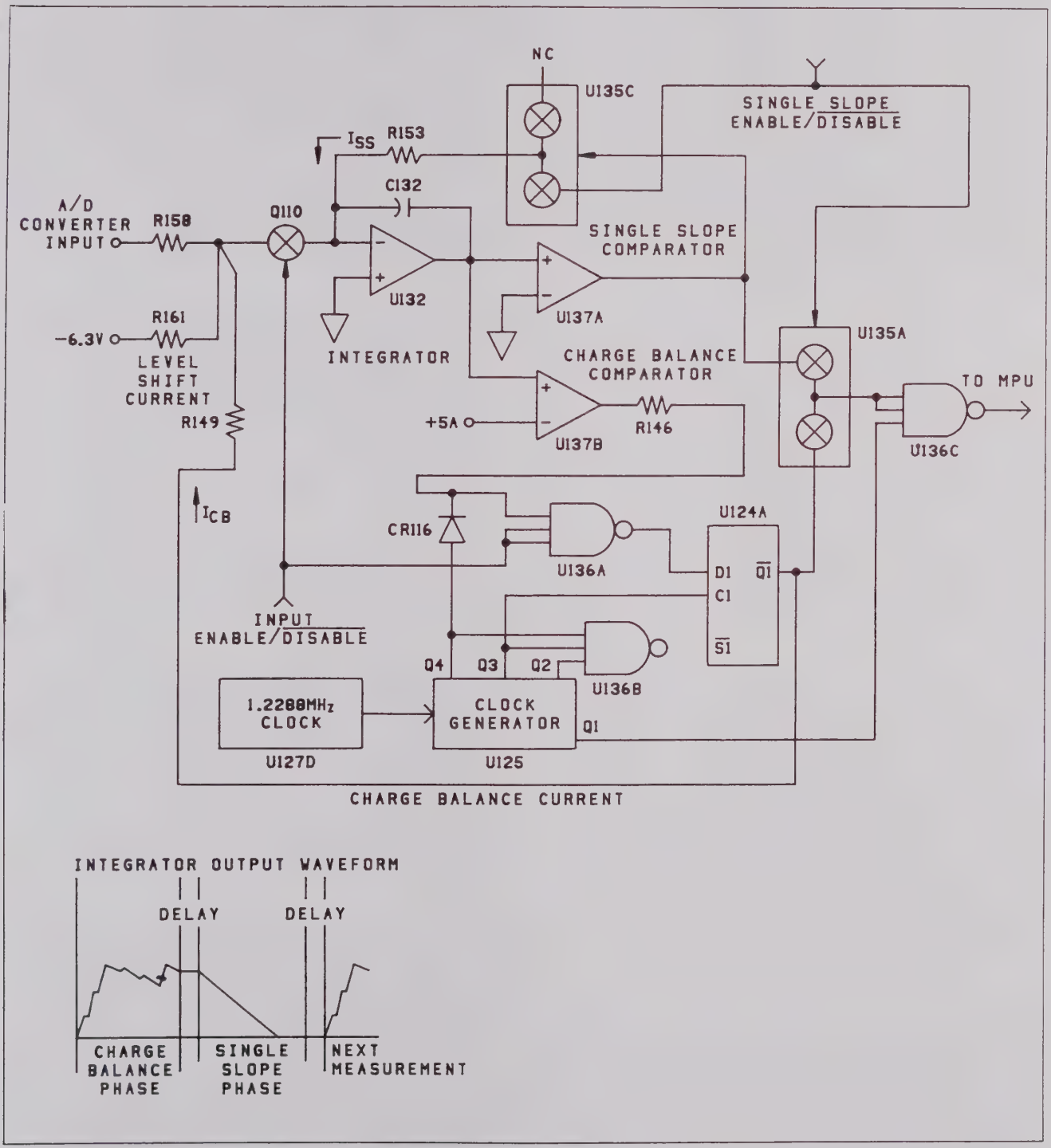


Figure 7-18. A/D Converter

The integrator is made up of U132 and C132. When the input to the integrator is applied, the integrator output ramps up until its voltage is slightly higher than the voltage to the inverting input of the charge balance comparator (U137B). When the Q3 output of the clock generator (U125) goes high, the output of U136A is low, and the Q1 output of U124A will go high. This action injects the charge balance current into the integrator input. Since the charge balance current is much larger than the sum of the input and level shift currents, the integrator output now ramps in the negative direction. The integrator output will continue to ramp in the negative direction until the output of U136B goes low. Note that the Q2, Q3 and Q4 outputs of U125 must all be high for the output of U136B to go low.

The output of U135A is gated with the Q1 output of the clock generator (U125) by U136C. Each time Q1 goes high while the U135A output is high, a pulse is fed to the microprocessor. The MPU then counts the total number of pulses that occur during the charge balance phase.

The charge balance phase lasts for one line cycle (16.67 or 20.0msec). At the end of this period, the output of the integrator is resting at some positive voltage. Since the integrator output is connected to the non-inverting input of the single-slope comparator (U137A), the single-slope comparator output remains high until the integrator output becomes negative.

During the single-slope phase, Q110 is turned off to disconnect the input and charge balance currents from the integrator input. In place of these two currents, the single-slope current s injected into the integrator input causing the output to ramp in the negative direction. This current is developed by connecting one end of R153 to +5V through U135C. As long as the integrator output remains positive, the Q1 pulses from U125 are transmitted to the microprocessor, where they are counted to be used in the final reading. Once the single-slope comparator output goes negative, the Q1 pulses are turned off by U136C.

7.10 DIGITAL CIRCUITRY

Model 595 operation is controlled by the internal microcomputer and associated software. The following paragraphs briefly describe the various aspects of the digital circuitry. Descriptions are keyed to the digital circuitry schematic (drawing number 595-106, page 2) located at the end of Section 9.

7.10.1 Microcomputer

Microcomputer operation centers around the 8 bit 146805 CMOS microprocessor, U109. The device utilizes an 8 bit data bus and incorporates a multiplexed data/address bus for the lower eight bits of the 12 bit address bus. The 146805 has 112 bytes of on-chip memory, two 8 bit I/O parts, and is capable of directly addressing 8K bytes of memory. The microprocessor unit has direct control over the display, front panel switches, analog-to-digital converter, the voltage source, the IEEE-488 bus, as well as the Meter Complete output and the External Trigger Input.

Microprocessor timing is performed by Y101, a 3.2768 MHz crystal. The signal is internally divided by five to obtain a bus operating frequency of 655.36kHz. This signal is present at the A5 terminal of the processor, and is used as a control signal to strobe the lower ordered eight bits of the address into the address latch, U108. A 655.36kHz signal is also present at the DS terminal to act as a system clock.

7.10.2 Memory Elements

Software for the Model 595 is stored in U106, a 27128 16K X 8 PROM. Temporary storage is afforded by U107, a 6116 2K X 8 RAM IC. The microprocessor unit uses the RAM for temporary storage.

Calibration constants, the display mode, and the IEEE-488 primary address are stored in the NVRAM, U104. During the power-up cycle, NVRAM data is transferred to normal RAM to allow easier access during operation. While data transmission to the ROM and RAM are done in parallel, NVRAM data transmission is performed serially.

7.10.3 Device Selection

The 146805 processor can directly address only 8K bytes of memory. The Model 595 requires greater addressing capability, as 16K of ROM, 2K of RAM, and other memory space requirements are present in the system. To get around this problem, device selection circuitry is incorporated with the micorcomputer.

Device selection is performed by elements of U111, U112, U116 and U117. Microprocessor unit lines used, part of the selection process, include the A10-A12 address lines, the

PB6 line, the PB7 line, and the DS line. Signals generated by this circuitry include a line which controls the ROM chip select, a signal line that controls the RAM chip select, and circuitry which enables the display control and IEEE-488 bus circuits. Additional device selection signals include the memory paging signals. Two signals divide the 16K ROM area into 4K pages, while a third signal divides the 2K RAM area into two 1K pages.

Because of the paging scheme employed, several devices can occupy a given address within the microprocessor's addressing space. Table 7-2 gives the general address range for each device.

Table 7-2. Memory Mapping

Device	Address Range
ANALOG OUT	$041A
RAM (U107)	$0000-$03FF
ROM (U106)	$0800-$1FFF
Display Control (U110)	$0432
Display Control (U114)	$042A
IEEE-488 Bus (U113)	$0418-$041F

7.10.4 IEEE-488 Bus

The Model 595 has a standard IEEE-488 interface that allows the instrument to be programmed from a system controller. Commands can be sent over the bus to the instrument, and data can be requested from the instrument as well.

The IEEE-488 interface is made up of U113, U118 and U119. U113 is a 9914 GPIA (General Purpose Interface Adapter), while U118 and U119 are 75161 and 75160 interface bus drivers, respectively.

The 9914 GPIA simplifies microprocessor unit interfacing to the IEEE-488 bus because many control sequences take place automatically. For example, when the microprocessor unit writes to the GPIA data output register, the handshake sequence is performed automatically. Without the GPIA chip, complex and time consuming microprocessor unit routines would otherwise be required.

On the microprocessor unit side of the GPIA, data transmission is handled much like any other data bus transaction. Microprocessor unit data access is performed through the D0-D7 lines, while the RS0-RS2 lines (which are connected to the three least significant address lines) serve to select among the 14 internal registers (seven read, seven write) of the integrated circuit. Chip selection is performed by the CS line.

The output of the 9914 IC is in standard IEEE-488 format; the eight data lines (DIO1 - DIO8), the three handshake lines (DAV, NRFD, NDAC), and the five management lines (ATN, REN, IFC, SRQ, and EOI) are all active low with approximately zero volts representing a logic one. The two IEEE-488 bus drivers, U118 and U119, are necessary to bring the drive capability of the interface up to the requirements of the IEEE-488 standard, which included provisions for up to 15 devices to be connected to the bus at one time. The outputs of the bus drivers are connected to J1012, which is a standard IEEE-488 connector.

7.10.5 Input/Output Circuitry

Additional microprocessor unit functions include the control of the Meter Complete and External Trigger Input, analog-to-digital converter control, and voltage source control.

At the end of its conversion cycle, the Model 595 sends a pulse out the Meter Complete jack on the rear panel. This function is performed by the PB2 line of the microprocessor unit through U102A configured as a buffer/inverter. Diodes CR104 and CR105 and resistor R102 protect the circuit output.

U102D, U105B, and associated components process the incoming trigger signal. U102D buffers and inverts the signal, while U105B latches the trigger pulse. The pulse is then read by the microprocessor unit through PB6. PB1 is used to reset the trigger latch once the pulse is read. Note that PB1 is also used to read the status of the calibration jumper (W101) during the calibration program.

As with the Meter Complete output, protection of the External Trigger input is necessary to protect the device from overvoltage inputs. External Trigger protection components include R101, CR102, and CR103.

A/D control information is fed out the PB3 and PB5 terminals through U102B. A pulse width modulation scheme is used with 18 and 50μsec pulses representing logic 0 and logic 1 respectively. A 200μsec pulse is used to strobe data into the A/D and serial-parallel control circuits. Note that this information is used to control the A/D converter as well as to control the input preamplifier (through relays), set the ranging amplifier gain, and to control the three phases of the measurement cycle. Isolation is provided by opto-isolator U121.

In a similar fashion, A/D data is routed in from the A/D converter through opto-isolator U120. The microprocessor unit reads this data through the timer terminal. As data pulses come in, an internal 8-bit timer is incremented until 256 counts have occurred. When all counts have been taken, an internal interrupt is generated, which causes the microprocessor unit to read the timer data. A separate software counter is then decremented, and the process repeats. Because of this data input scheme, microprocessor unit time necessary to read the A/D converter data is minimized, and the processor can concentrate on other important tasks.

The voltage source is controlled in a manner similar to that used to control the A/D converter. Control information is transmitted out the PB3 and PB5 terminals of the microprocessor unit through U102B. Once again, a pulse width modulation scheme is used to transmit the 12 bit data necessary to control the DAC in the voltage source section.

Voltage source overload data is fed in through opto-isolator U122 to PA7 terminal of the microprocessor unit. When the 2mA current limit of the voltage source is exceeded, PA7 goes high. The necessary software routine is used to flash the DISPLAY SOURCE LED, indicating to the operator that an overload has occurred.

7.10.6 Display Circuitry

Display circuitry includes those elements necessary to control the seven and 14 segment readouts, the front panel annunciator LEDs, and to read the front panel switches. The display circuitry schematic may be found on drawing number 595-116, located at the end of Section 9.

The display circuitry consists of the LED readouts (DS201 - DS206), the LED annunciators (DS207 - DS223), the segment drivers (U201 and U202) and the digit select circuitry (U203, U204 and U205). DS202 - DS205 are standard 7-segment units, while DS206 is a dual 14-segment display.

The display is updated at 1.56msec intervals. Timing for this process is performed by a 640Hz clock which controls the segment latches, U110 and U114, located on the mother board. Each time an interrupt is generated, the microprocessor unit writes segment data for two digits to the segment latches. The two latches outputs are then enabled in sequence by the 640Hz clock.

When a latch output is enabled, segments in the selected digit are turned on.

When a latch output is selected, segments in the selected digit are turned on. Digit selection is performed by data from the PA3, PA4, and PA5 outputs of the microprocessor unit to control U203. A single U203 output, corresponding to the selected digit, will go low when the correct data appears on its inputs. For example, if 010_2 appears on the inputs of U203, DS201 will be turned on.

Selection of the display annunciators is performed in a similar manner. The data stored in the corresponding segment latches will then turn on the appropriate annunciator LEDs.

Front panel switches are read in a somewhat similar manner by using a row-column matrix along with U206. To select a particular row, data is transmitted out the microprocessor unit PA3, PA4 and PA5 lines to U206. This action selects one of the rows by placing the corresponding output of U206 high. Matrix columns are then read by reading data in through PA0, PA1, and PA2, of the microprocessor unit. If a particular switch contact is closed, the data bit will be high; if the switch is open, the data bit will be low.

7.11 ANALOG OUTPUTS

The Model 595 provides analog outputs proportional to V and C, Q/t or I for plotting curves on analog X-Y recorders. The analog outputs are reconstructed from the digital readings using a pair of D/A converters. The converters have ±2V full range outputs with 1kohm output impedance and are referrenced to IEEE-488 bus common.

A simplified circuits of the analog outputs are shown in Figure 7-19. Note that the circuits for the both the C,I analog output and the V analog output are identical. Thus, the following functional description of the C,I analog output circuit also applies for the V analog output circuit.

U308 is a multiplying current output converter. A 12-bit digital value is programmed through the inputs of the device. This digital value detemines what proportion of the output current is switched to OUT1 and what is switched to OUT2. The sum of OUT1 and OUT2 is always V_{ref}/R_f.

U309 is an operational amplifier that is used to convert the current from OUT1 to a voltage, with the internal R_f of U308 as its feedback resistor. With U309 alone, the D/A output would be unipolar, from 0 to −4V. However, U310, R334 and R335 are used to invert the current from OUT2 which is then summed with OUT1 at the summing node of U309. This causes the output swing to be bipolar form −4V to +4V. R336 and R337 attenuates the outputs to −2V and +2V.

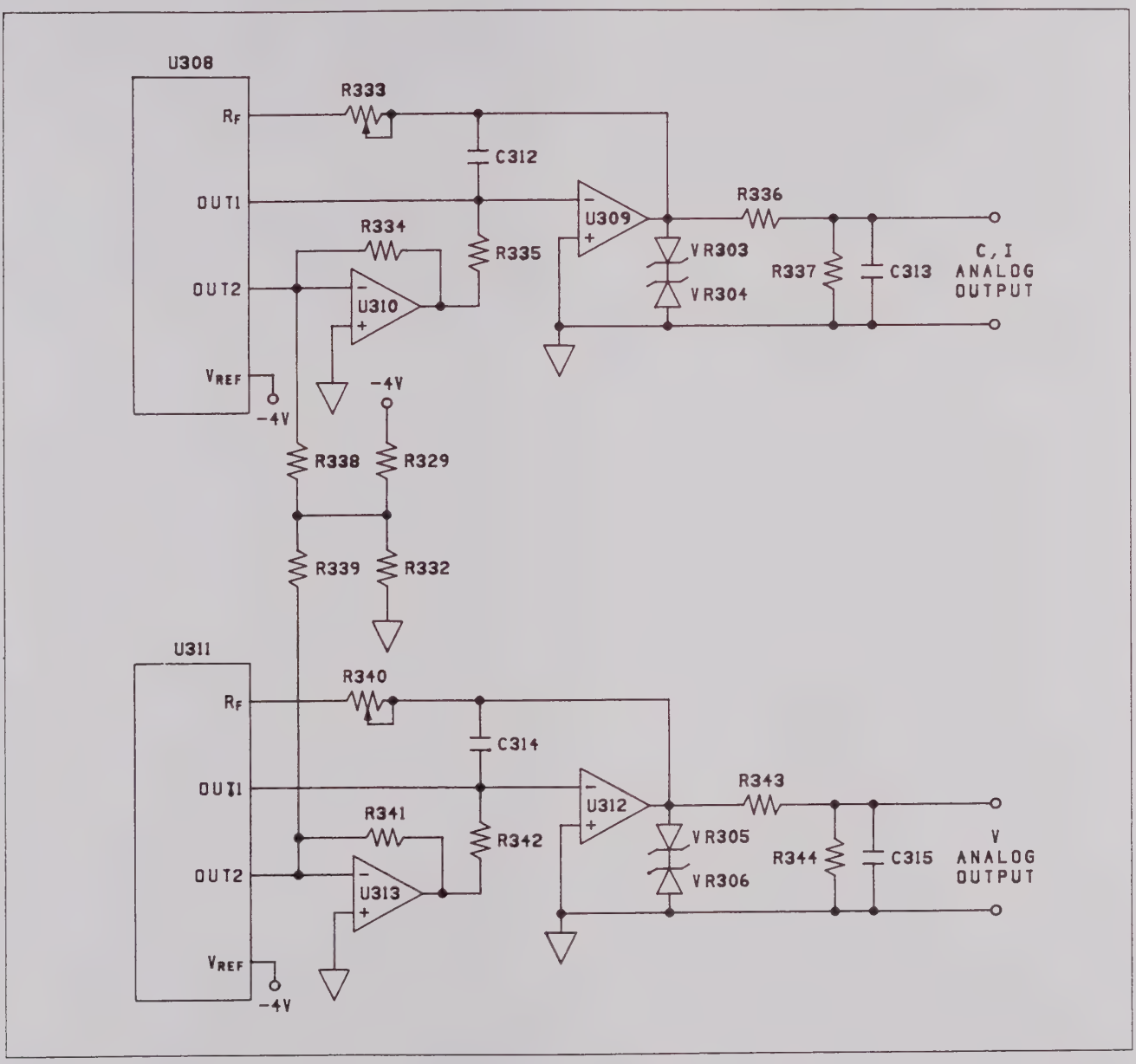


Figure 7-19. Analog Outputs

7.12 MAIN POWER SUPPLY

The diagram for the main power power supply is located on drawing 595-106, page 1. AC power is applied to J1013, which is the power connector located on the rear panel of the instrument. S101 is the POWER switch located on the front panel, while S102 is the line voltage selection switch. When S102 is in the 115V position, the primary windings are connected in parallel; when S102 in in the 230V position, the T102 windings are placed in series.

T102 has three secondary windings which are used to supply the ±24V, ±15V and +5V supplies. The ±24V and ±15V sources supply the voltage source analog outputs, preamplifier, and the +5V supplyis used for the digital circuitry.

The ±24V supplies consist of half-wave rectifier diodes (CR108 and CR107) and filter capacitors (C110 and C111). Each of the ±15V supplies has a similar half-wave rectification scheme (CR101 and C103 for the −15V supply, CR109 and C108 for the +15V supply). Regulation for these supplies is performed by U144 and U143, which are IC regulators.

The third winding of T102 supplies the +5V (+5D) source that is used to power the digital circuits. Rectification is done by elements of CR110, while filtering is performed by C101. The supply voltage is regulated by U101, which is a standard 7805 IC regulator.

SECTION 8
MAINTENANCE

8.1 INTRODUCTION

This section contains information necessary to maintain, calibrate, and troubleshoot the Model 595. Fuse replacement and line voltage selection procedures are also included.

WARNING

The procedures included in this section are for use only by qualified service personnel. Do not perform these procedures unless qualified to do so. Many of the steps in this section may expose you to potentially lethal voltages that could result in personal injury or death if normal safety precautions are not observed.

8.2 LINE FREQUENCY SELECTION

The Model 595 may be operated at a line frequency of either 50 or 60 Hz. The instrument's frequency may be set with the front panel line frequency program. To access the program and set the frequency, proceed as follows:

1. Hold in the MENU button while pressing the POWER button to turn on the instrument.
2. Press the MENU button until the message "Fr=" appears on the display.
3. Press either voltage source ADJUST button to toggle frequency between 50 and 60Hz.
4. When the desired frequency is displayed, press SHIFT, then EXIT to lock in frequency selection. Note: Line frequency selection is stored in permanent memory.

8.3 LINE VOLTAGE SELECTION

The Model 595 may be operated from either 105-125V or 210-250V 50 or 60Hz power sources. A special transformer may be installed (at factory) for 90-110V and 195-235V ranges. The instrument was shipped from the factory set for an operating voltage marked on the rear panel. To change the line voltage, proceed as follows.

WARNING

Disconnect the Model 595 from the power line and all other sources before removing the top cover.

1. Remove the screws securing the top cover to the rear panel and carefully lift the cover away from the instrument.
2. Locate the line voltage switch adjacent to the POWER switch on the mother board. Place the switch in the correct position, as outlined in Table 8-1.
3. Install a fuse consistent with the operating voltage, as described in paragraph 8.4.

CAUTION

The correct fuse type must be used to maintain proper instrument protection.

4. Mark the selected line voltage on the rear panel for future reference (to avoid confusion, erase any old marks).
5. Replace the top cover and connect the instrument to the power line.

Table 8-1. Line Voltage Selection (50-60Hz)

Line Voltage	Voltage Selection Switch Position
105 - 125V	110V
210 - 250V	220V
90 - 110V*	110V
195 - 235V*	220V

*Requires special power transformer, installed at the factory.

8.4 FUSE REPLACEMENT

A rear panel fuse protects the power line input of the instrument. Use the following procedure to replace the line fuse.

WARNING
Disconnect the instrument from the power line and other equipment before replacing the fuse.

1. With the power off, place the end of a flat-blade screwdriver into the slot in the rear panel LINE FUSE holder. Push in gently and rotate the fuse carrier one-quarter turn counterclockwise. Release pressure on the holder and its internal spring will push the fuse and carrier out of the holder.
2. Remove the fuse and replace it with the type recommended in Table 8-2.

Table 8-2. Line Fuse Selection

Line Voltage	Fuse Type	Keithley Part Number
90-125V	1/8A, 250V, 3AG, Slo Blo	FU-20
195-250V	1/16A, 250V, 3AG, Slo Blo	FU-21

CAUTION
Do not use a fuse with a higher current rating than specified, or instrument damage may occur. If the instrument repeatedly blows fuses, locate and correct the cause of the trouble before replacing the fuse.

3. Install the new fuse and the fuse carrier into the holder by reversing the above procedure.

8.5 CALIBRATION

Much of the calibration procedure for the Model 595 is digital in nature. Instead of the time-consuming method of adjusting numerous calibration potentiometers, the technician need only apply an appropriate calibration signal and digitally calibrate the instrument, either from the front panel or over the IEEE-488 bus.

Some of the calibration procedures will require a shielded test fixture. Construction of this fixture is detailed in Figure 8-1. The fixture should be used wherever a shielded enclosure is called for at various places in the procedure.

Calibration should be performed every 12 months, or if the performance verification procedures in Section 6 show that the instrument is out of specification. If any of the calibration procedures cannot be performed properly, refer to the troubleshooting information in this section.

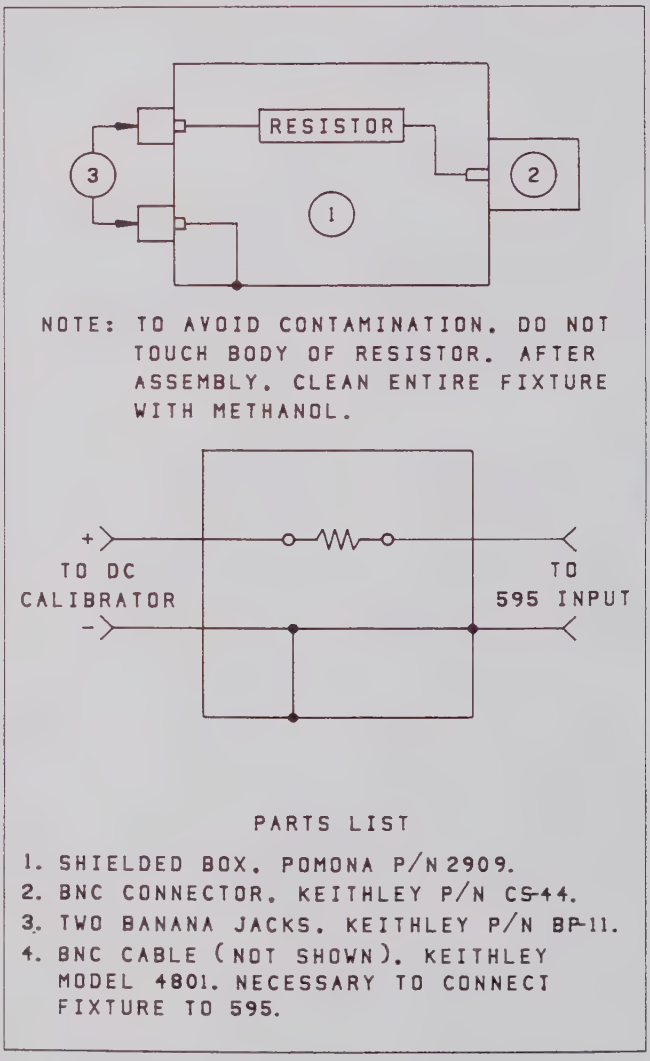

RESISTOR
3
2
1
NOTE: TO AVOID CONTAMINATION, DO NOT TOUCH BODY OF RESISTOR. AFTER ASSEMBLY, CLEAN ENTIRE FIXTURE WITH METHANOL.
+
TO DC CALIBRATOR
-
TO 595 INPUT
PARTS LIST
1. SHIELDED BOX, POMONA P/N 2909.
2. BNC CONNECTOR, KEITHLEY P/N CS-44.
3. TWO BANANA JACKS, KEITHLEY P/N BP-11.
4. BNC CABLE (NOT SHOWN), KEITHLEY MODEL 4801, NECESSARY TO CONNECT FIXTURE TO 595.

Figure 8-1. Test Fixture Construction

8.5.1 Recommended Calibration Equipment

Table 8-3 lists recommended calibration equipment. Alternate equipment may be used as long as equipment accuracy is at least as good as the specifications listed in the table.

Table 8-3. Recommended Calibration Equipment

Description	Specifications	Manufacturer and Model
DC Calibrator	0.19V, 1.9V, ±0.002%	Fluke; 343A
5½ Digit DMM	±0.015% DC Accuracy	Keithley; 197
Teraohmmeter	100MΩ, ±0.035% 10GΩ, ±0.07%	Guildline; 9520
Resistor	100MΩ, ±1%	Keithley; R-289-100M
Resistor	10GΩ, +0, −2%	Keithley; R-319-10G
Decade Resistor	10Ω-10MΩ, ±.03%	ESI; DB-62
Characterized Capacitors	18nF, 1.8nF, 180pF	Keithley; 5955
Shielded Test Box		See Figure 8-1
BNC Cable		Keithley; 4801 (supplied with 595)
BNC to Banana Plug Adapter		Pomona; 1269
Banana Plug to BNC Adapter		Pomona; 1296

8.5.2 Environmental Conditions

Calibration should be performed under laboratory conditions having an ambient temperature of 23°C ±1°C and a relative humidity of less than 70%.

8.5.3 Warm-Up Period

Turn on the instrument power and allow it to warm up for at least two hours before beginning the calibration procedure. (Note: Wait at least eight hours before attempting input current calibration.) If the instrument has been subjected to extremes of temperature or humidity, allow at least one additional hour for the instrument to stabilize before beginning the calibration procedure. Typically, it takes one additional hour to stabilize a unit that is 10°C (18°F) outside the specified temperature range.

NOTE

While rated accuracy is achieved after the two hour warm up period, input bias current may require additional time to come to its optimum level. Allow two hours for input bias current to settle to less than 10fA and eight hours to less than 5fA. It is preferable in sensitive applications to leave the unit on continuously.

8.5.4 Calibration Jumper

A jumper, located on the mother board, allows the technician to disable or enable front panel and IEEE-488 bus calibration. When the jumper is in the disable position, permanent storage of calibration constants will not take place. However, temporary calibration values may be entered and used even if permanent calibration storage is disabled. Note, however, that any calibration parameters will be lost once the power is turned off, unless they are permanently stored in nonvolatile memory (NVRAM).

The calibration jumper location is located on the mother board near the AC line receptacle (see Figure 8-2). The disable/enable positions are also shown in Figure 8-2. Note that the jumper is in the disable position as shipped from the factory.

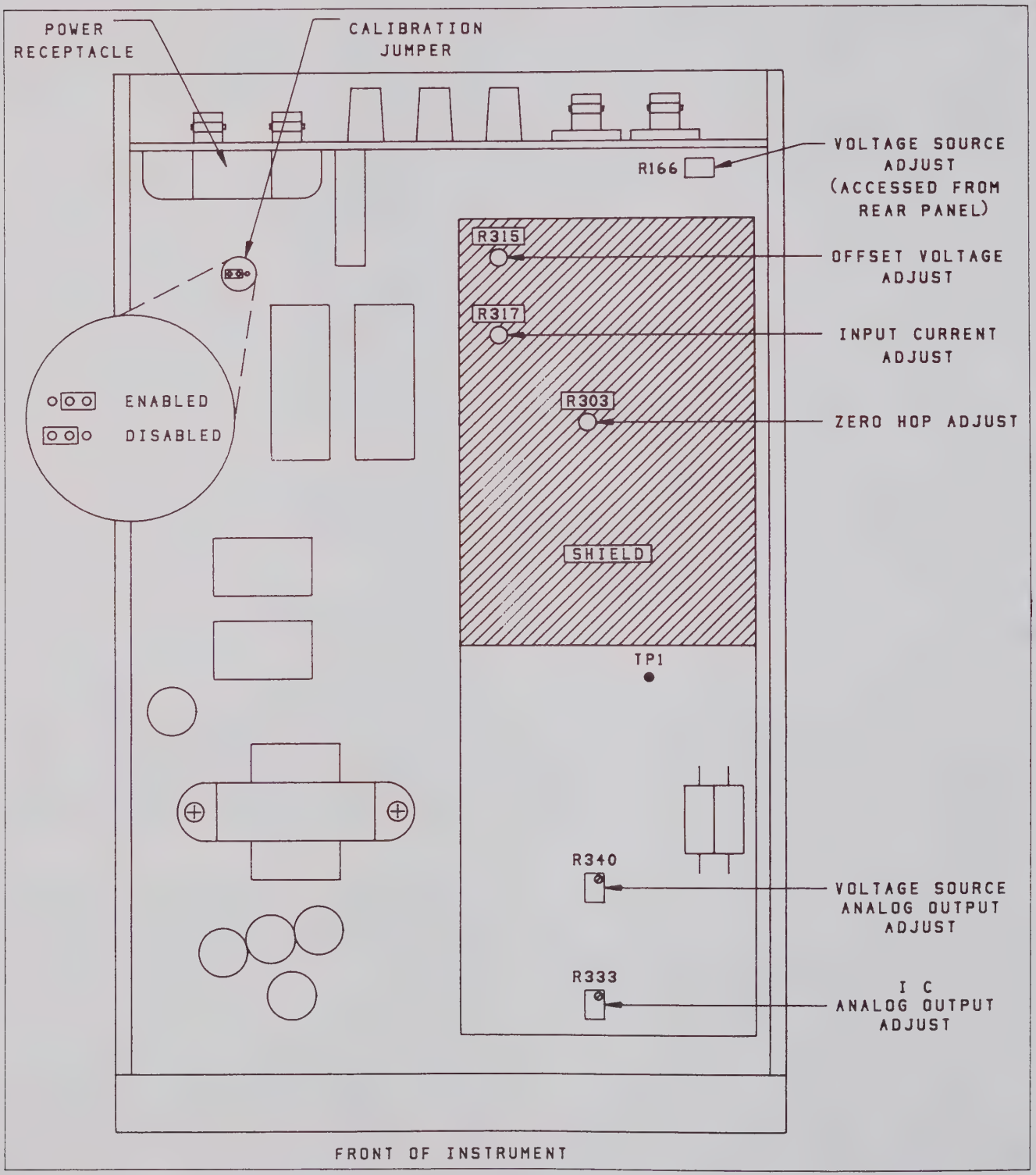


Figure 8-2. Calibration Jumper and Calibration Pots

8.5.5 Front Panel Calibration

The following information provides the general procedure for digitally calibrating the instrument from the front panel. This is not the detailed calibration procedure and is only intended to acquaint the technician with the general techniques of front panel calibration. The detailed calibration procedure, which includes the manual adjustments, starts at paragraph 8.5.7.

With the instrument in the calibration program (see paragraph 8.5.8), front panel (digital) calibration is performed as follows:

1. Select the function and range to be calibrated.
2. For current calibration, zero correct the instrument. Zero correction is not necessary for capacitance calibration.
3. Set calibrator to 0V or cap the input for capacitance calibration. Disable ZERO CHECK and after allowing the reading to settle, press SUPPRESS.
4. Apply the calibration source to the instrument.
5. Using the voltage source ADJUST buttons, set the display to agree with the actual calibration source value. For example, for a calibration source value 1.9000μA, set the display to read 1.9000 μA. (Note that the decimal points in the exponent annunciators indicate that the calibration program is selected).
6. Repeat steps 1 through 5 for each function/range to be calibrated.
7. To store the calibration points in memory, press the MENU button.
   A. With the calibration jumper in the enable position, the "Stor" message will be displayed briefly indicating that the calibration points have been stored into permanent (NVRAM) memory. The instrument will then exit the calibration program.
   B. With the calibration jumper in the disable position, the "out" message will be displayed briefly and the instrument will exit the calibration program. The blinking exponent decimal points indicate that the calibration points have been stored in temporary (RAM) memory. These temporary calibration points will be lost when the instrument is turned off. The previous permanent calibration points will prevail when the instrument is again turned on.

   Note: The calibration program (CAL) remains on the program menu as long as the instrument remains on. This allows the technician to select the calibration program without turning off the instrument and subsequently losing temporary calibration points.

8.5.6 IEEE-488 Bus Calibration

The following information provides the general procedure for entering calibration points over the IEEE-488 bus. This is not the detailed calibration procedure and is only intended to acquaint the technician with the general techniques of IEEE-488 bus calibration. The detailed calibration procedure, which includes the manual adjustments, starts at paragraph 8.5.7.

IEEE-488 bus calibration is similar to front panel calibration except that calibration values are transmitted over the bus instead of being entered from the front panel. Also, a separate command is included to perform permanent storage. By combining appropriate IEEE-488 compatible calibration equipment with a suitable test program, digital calibration of the Model 595 could be performed on an automated basis.

Calibration points are sent to the Model 595 over the IEEE-488 bus as follows:

1. Program the desired range over the bus. For example, to select the 2nA range and current function, send F1R3X.
2. For current calibration, zero correct the instrument by sending Z2X. Zero correction is not necessary for capacitance calibration.
3. Set calibrator to 0V or cap the input for capacitance calibration. Disable ZERO CHECK and after allowing the reading to settle, enable SUPPRESS.
4. Apply the calibration source to the input jack.
5. Send the required calibration value preceded by the A command letter. For example, to calibrate the 20nA range at the 19nA calibration point, send A19E-09X. Note that the exponent decimal points will blink indicating that temporary storage has occured.
6. Repeat steps 1-5 for the remaining ranges and functions.
7. After all points have been calibrated, send J19X to permanently store calibration constants. Note that even though it is most practical to send the storage command (J19X) after all calibration commands have been sent, the storage command can be sent after each calibration command.

NOTE

Permanent storage of calibration constants will not take place if the calibration jumper is in the disabled position. See paragraph 8.5.4 for details.

HP-85 Programming Example—The simple program below will allow you to send the desired calibration command string to the Model 595. The program assumes that the instrument primary address is at its default value of 28.

PROGRAM	COMMENTS
`10 REMOTE 728`	Send remote enable.
`20 DISP "CALIBRATION COMMAND"`	Prompt for command.
`30 INPUT A$`	Input command string from keyboard.
`40 OUTPUT 728;A$`	Send command string to 595.
`50 GOTO 20`	Repeat.
`60 END`	

To run the program, press the HP-85 RUN key. At the command prompt, type in the desired calibration command and press return. For example, to perform permanent calibration constant storage, type in J19X and press return. To stop the program, press the HP-85 PAUSE key.

8.5.7 Calibration Sequence

Model 595 Calibration must be performed in the order given in the following paragraphs, with the exception of voltage source calibration, which can be done at any time. The basic sequence is:

1. Input offset voltage adjustment (paragraph 8.5.9)
2. Zero Hop Compensation (paragraph 8.5.10)
3. Input current adjustment (paragraph 8.5.11)
4. Capacitance offset compensation (paragraph 8.5.12)
5. Voltage source calibration (paragraph 8.5.13)
6. Current calibration (paragraph 8.5.14)
7. I,C analog output adjustment (paragraph 8.5.15)
8. Q/t calibration (paragraph 8.5.16)
9. Capacitance calibration (paragraph 8.5.17)

In addition to the above sequence, the ranges for each function must be calibrated in the order given.

Notes:

1. Never calibrate a range using a suppress value taken on a different range.
2. The top cover will have to be removed to make internal adustments. To help maintain a proper internal temperature level, keep the top cover on the instrument when not making internal adjustsments.

8.5.8 Digital Calibration

If digital calibration is to be performed from the front panel, the instrument will have to be placed in the calibration program. If digital calibration is going to be done over the IEEE-488 bus, the instrument enters the calibration mode automatically when the calibration command (A) is sent.

For front panel digital calibration, select the calibration program as follows:

1. Turn off the Model 595.
2. While holding in the program MENU button, power up the Model 595.
3. After the display blanks for approximately one second, let go of the MENU button. The calibration program is now included in the program menu and will remain there as long as the instrument remains on.
4. Repeatedly press the MENU button until the following message is displayed:

   CAL

5. With the "CAL" message displayed, release the MENU button. The instrument is now in the calibration program as indicated by the displayed exponent decimal points.

8.5.9 Input Offset Voltage Adjustment

Use the following procedure to null out any small offset voltage. Input offset adjustment is particularly critical if input voltage burden is a consideration since any offset will increase the voltage burden, as seen by the input signal.

NOTE

If the following adjustment cannot be made, the input stage will need to be balanced. Usually, balancing only needs to be done if the input FET or an associated component is replaced. To balance the input stage, perform the procedure in paragraph 8.9.

1. Disconnect all input signals from the instrument and cap the METER INPUT connector. Make sure the GUARD to chassis ground link is installed.
2. Remove the two screws securing the top cover and remove the cover from the instrument.
3. Select the current function and place the instrument on the 20pA range.
4. Enable ZERO CHECK.
5. Using the DMM set to the 200mVDC range, monitor Test Point 1 (TP1) on the preamp board (see Figure 8-2) referenced to GUARD. Locate the offset adjustment potentiometer (R315) on the preamp board. The pot is accessible through a small hole in the shield closest to the rear of the instrument.
6. Adjust R315 for a reading of 000.000mV ±.010mV on the DMM.

8.5.10 Zero Hop Compensation

Zero hop is adjusted at the factory and need not be performed unless components in the compensation circuitry were replaced or if pot R303 was accidentally adjusted.

Equipment Needed: Oscilloscope with a X1 probe and an RC filter. See Figure 8-3 for filter component values and setup.

Perform the following procedure to adjust zero hop:

1. Set the Model 595 to the capacitance function, 200pF range, 0.07 S delay, 0.05 SQ Step V and enable ZERO CHECK.
2. Connect the 180pF capacitor to the input of the Model 595.
3. Turn pot R303 (see Figure 8-2) fully counter clockwise.
4. Set the scope to 0.1V/div., DC coupled and 20mS/div., and monitor the waveform at TP1 with respect to GUARD.
5. Adjust the scope so that the straight line trace is at the center of the CRT (0V).
6. Disable ZERO CHECK and turn R303 clockwise until the adjustable portion of the trace is at 0V.
7. Enable ZERO CHECK, set the scope sensitivity to 5mV/div and again center the straight line trace to the center of the CRT (0V).
8. Disable ZERO CHECK and adjust R303 until the adjustable portion of the trace is within one division (±5mV) of the 0V line.

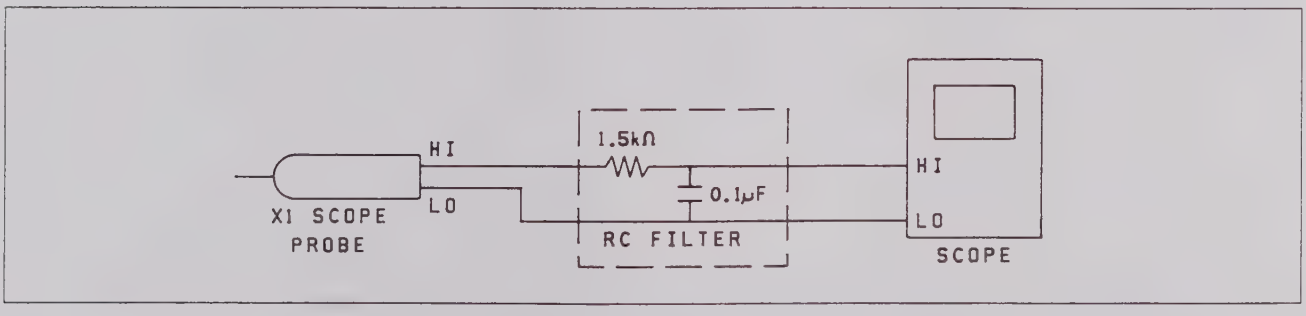


Figure 8-3. Equipment for Zero Hop Compensation

8.5.11 Input Current Adjustment

Use the following procedure to null out any input current present in the input stage. The input current will then be automatically temperature compensated to reduce the effects of high ambient temperature. Low input current is particularly important when making very low current measurements. Proceed as follows:

1. Disconnect all input signals from the instrument. Place the protection cap on the METER INPUT connector.
2. Remove the two screws securing the top cover and remove it from the instrument.

NOTE

The proper warm up should be allowed. The top cover must not be removed for more than five minutes before adjustment.

3. Select the current function and place the instrument on the 20 pA range. Select filter 3 and set delay time to 0.2sec.
4. Enable ZERO CHECK and CORRect in that order.
5. Disable ZERO CHECK.
6. Wait several minutes until the displayed reading settles down; about 2 counts (2fA) peak-to-peak noise is normal.
7. Locate the input current potentiometer R317 on the preamp board (see Figure 8-2). It is accessible through a small hole in the shield.
8. Carefully adjust R317 for a reading of 0.000 ±2 counts on the display. Repeated adjustment may be necessary.

Note: Remember to keep the top cover on the instrument when not making internal adjustments.

8.5.12 Capacitance Offset Compensation

Perform the following digital calibration procedure to compensate for capacitance offset from the front panel. For front panel calibration, skip step 4. For IEEE-488 bus calibration, skip step 3.

1. Select the 200pF range, filter 3, 0.07 second delay and 0.01V squarewave step. Disable ZERO CHECK if it is on.
2. Place the protection cap on the METER INPUT connector.
3. For front panel calibration:
   A. Make sure the calibration program is selected.
   B. Press SHIFT and then the SELECT ▼ button. The display should settle to a reading of 00.00 pF ±2 counts.
   C. Press the ADJUST ▲ or ▼ button.
4. For IEEE-488 bus calibration, perform steps 1 and 2, and then send J16X over the bus.

Compensation is now stored in temporary memory. If it is desired to store the calibration constants in permanent memory at this time, perform the procedure in paragraph 8.5.18. Usually, it is most practical to complete the entire calibration procedure before performing the storage procedure.

8.5.13 Voltage Source Calibration

Use the following procedure to calibrate the voltage source. Voltage source calibration can be performed at any time, separate from meter calibration.

1. Connect the DMM to VOLTAGE SOURCE OUTPUT, as shown in Figure 8-4.
2. Set the voltage source to output 00.00V.
3. Turn on the voltage source output by selecting the DC WAVEFORM.
4. Place the DMM on the lowest DC voltage range possible without overranging the instrument and verify an output voltage of 0V ±10mV.
5. Enable REL on the DMM to cancel the voltage offset.
6. Set the DMM to the 20V (or similar) range and set the voltage source to output 19.00V.
7. Adjust R166 (accessable from the rear panel - see Figure 8-2) for a DMM reading of 19.000V ±1mV.
8. Set the voltage source to output 00.00V, disable SUPPRESS, and connect the DMM to V ANALOG OUTPUT as shown in Figure 8-5.
9. Verify that the DMM reads 0V ±2mV.
10. Enable REL on the DMM and set the voltage source to output 19.00V, in that order.
11. Adjust R340 (see Figure 8-2) for a DMM reading of 1.9000V ±100μV.
12. Turn off the voltage source output and disconnect the DMM.

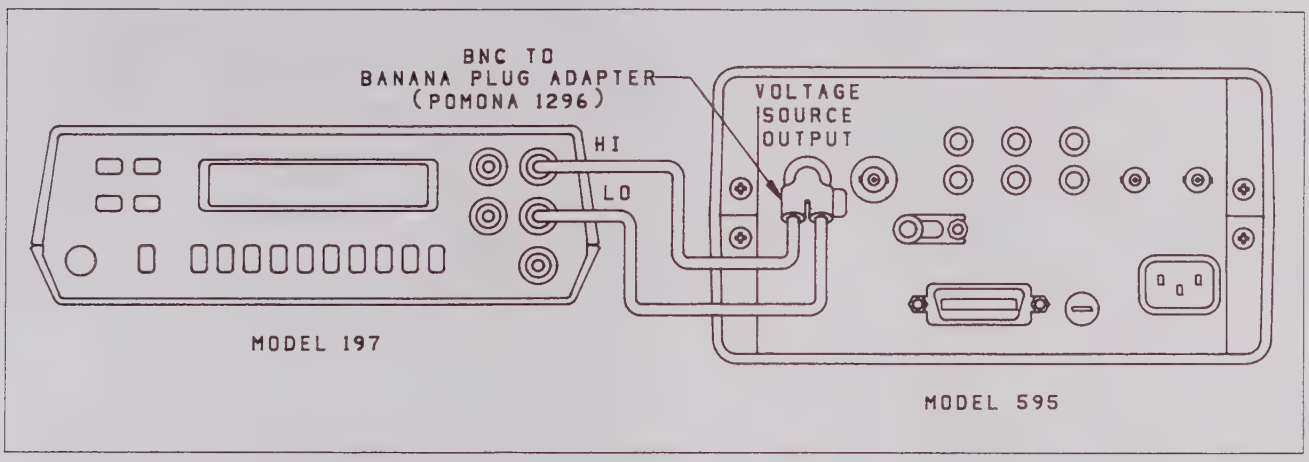


Figure 8-4. Voltage Source Output Calibration Setup

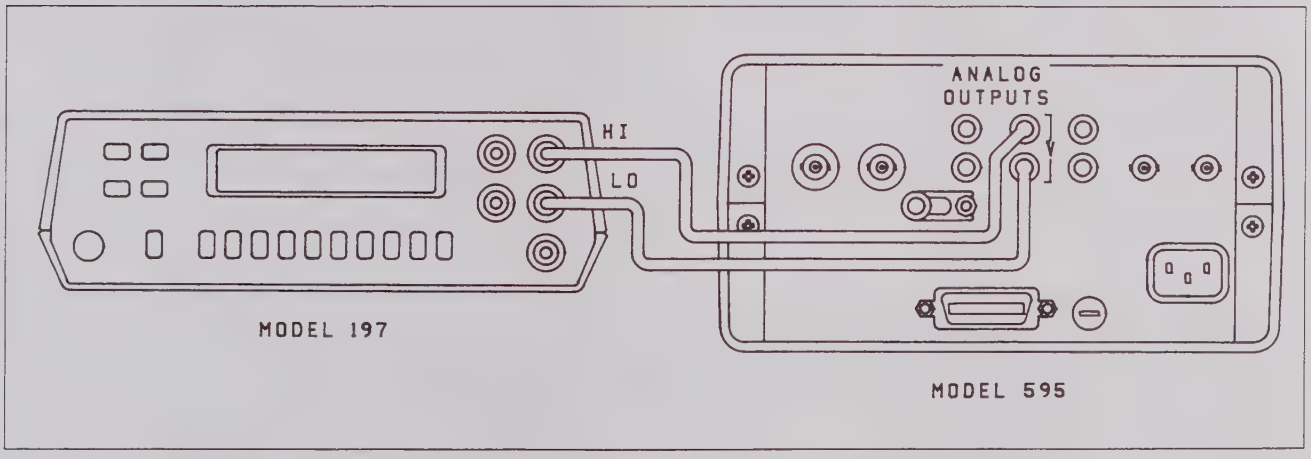


Figure 8-5. V Analog Output Calibration Setup

Table 8-4. Current Calibration

595 Range	Calibration Current	Test Setup	Filter	Resistor Value*	DC Calibrator Voltage	595 Calibration Point	IEEE-488 Bus Command
200pA	190.00 pA	Figure 8-6	2	(10 GΩ) _____	(1.9V) _____	190.00 pA	A190E-12X
20nA	19.000 nA	Figure 8-6	2	(100MΩ) _____	(1.9V) _____	19.000 nA	A19E-9X
2 μA	1.9000 μA	Figure 8-7	0	10.00MΩ	19.0000V	1.9000 μA	A1.9E-6X
20 μA	19.000 μA	Figure 8-7	0	1.000MΩ	19.0000V	19.000 μA	A19E-6X
200 μA	190.00 μA	Figure 8-7	0	100.00kΩ	19.0000V	190.00 μA	A190E-6X

*Values in parenthesis are nominal values. See text for methods to determine these values.

8.5.14 Current Calibration

Digital calibration of the current function should be performed on these particular ranges in the following order: 200pA, 20nA, 2μA, 20μA, and 200μA ranges. Once these ranges are calibrated, the remaining current ranges are automatically calibrated.

Using Table 8-4 as a guide, proceed as follows:

1. Using the teraohmmeter, accurately measure the values of the 10GΩ and 100MΩ resistors. Record the values in the first and second lines of Table 8-4. Using these values, calculate each calibration voltage as follows:

   $$E = I \times R$$

   Where I is the calibration current and R is the measured resistance value. Record the calculated calibrator voltages in the table. For example, if the actual resistance value of the 10GΩ resistor is 10.1GΩ, the calibrator voltage value would be 1.919V.

   NOTE
   Do not touch the body of the resistors. Contamination could give erroneous results.

2. Place the instrument in the current function, 200pA range, and select FILTER 2. Make sure the calibration program is selected if calibration is to be done from the front panel.
3. Zero correct the instrument by enabling ZERO CHECK and performing CORRect in that order.
4. Connect the DC calibrator and 10GΩ resistor to the Model 595, as shown in Figure 8-6. Note that the resistor is to be placed in a shielded enclosure, as shown on the diagram. (See Figure 8-1 for recommended shield).
5. Set the calibrator to output 0V.
6. Disable ZERO CHECK, allow the reading to settle and enable SUPPRESS in that order.
7. Set the calibrator to output the voltage listed in Table 8-4 for the 200pA range.
8. Perform one of the following operations to digitally enter the calibration value:
   A. From the front panel, adjust the display to read 190.00pA using the voltage source ADJUST buttons.
   B. Over the IEEE-488 bus, send A190E-12X.
9. Enable ZERO CHECK, disable SUPPRESS, and set the calibrator output to 0V.
10. Remove the 10GΩ resistor from the test fixture and install the 100MΩ resistor.
11. Select the 20nA range, disable ZERO CHECK, allow the reading to settle and enable SUPPRESS in that order.
12. Set the calibrator to output the voltage listed in Table 8-4 for the 20nA range.
13. Perform one of the following operations to digitally enter the calibration value:
    A. From the front panel, adjust the display to read 19.000nA.
    B. Over the bus, send A19E-9X.
14. Enable ZERO CHECK, disable SUPPRESS, and set the calibrator to output 0V.
15. Disconnect the resistor/shield fixture from the instrument and connect the decade resistance box in its place, as shown in Figure 8-7.
16. Set the decade box to the resistor value listed for the 2μA range in the table.
17. Select the 2μA range and FILTER 0 (disabled).
18. Disable ZERO CHECK and enable SUPPRESS in that order.
19. Set the calibrator to the voltage value listed for the 2μA range in the table.
20. Set the calibration constant to exactly 1.9000μA, either from the front panel or over the IEEE-488 bus.

21. Enable ZERO CHECK, disable SUPPRESS and set the calibrator to output 0V.
22. Using Table 8-4, repeat steps 16 through 21 for the 20μA and 200μA ranges. For maximum accuracy, remember to re-apply suppression after each range is selected with 0μA on the input (calibrator output at 0V).

Current calibration constants are now stored in temporary memory. If it is desired to store the calibration constants in permanent memory at this time, perform the procedure in paragraph 8.5.18.

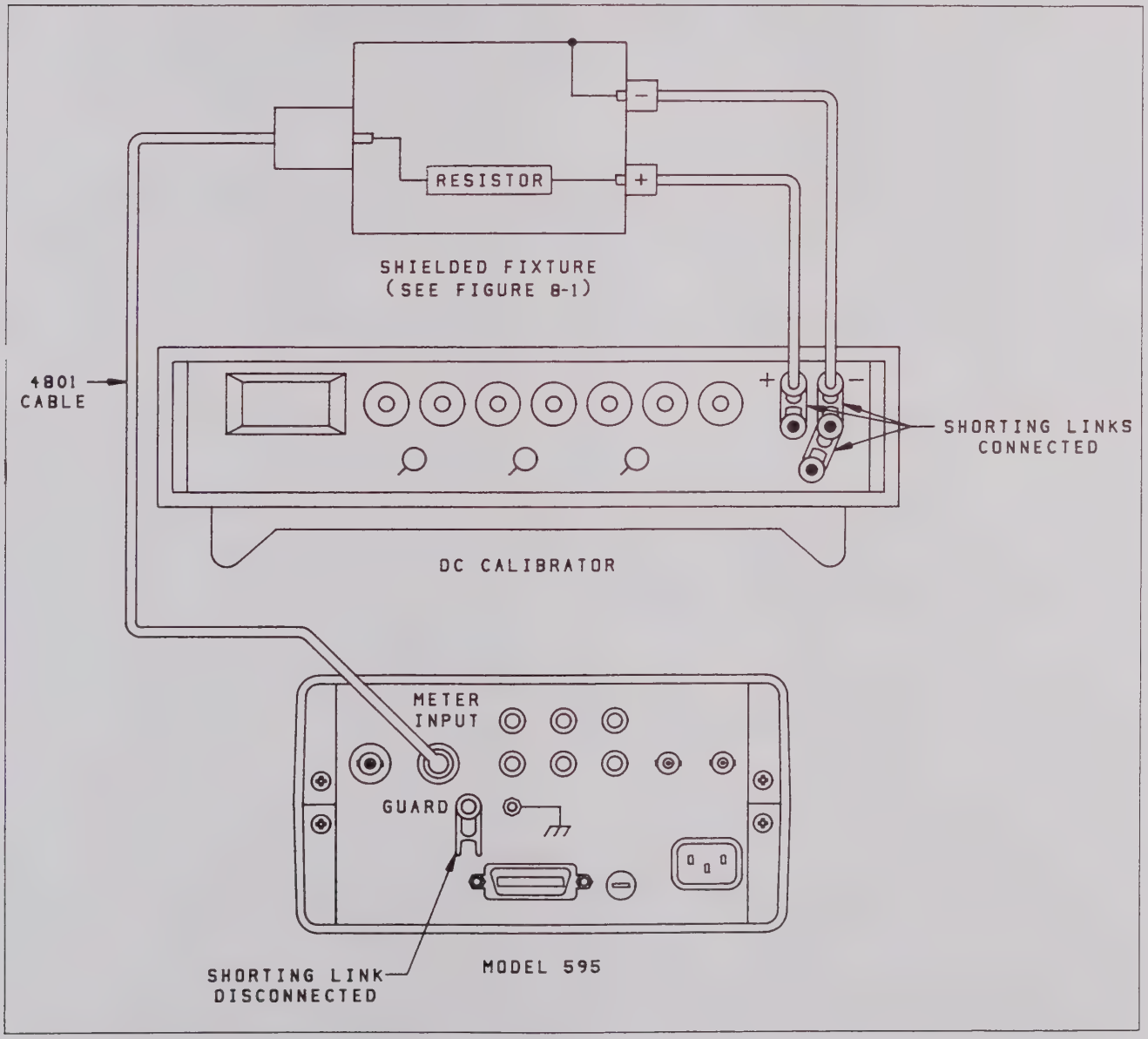


Figure 8-6. Current Calibration Setup (200pA and 20nA Ranges)

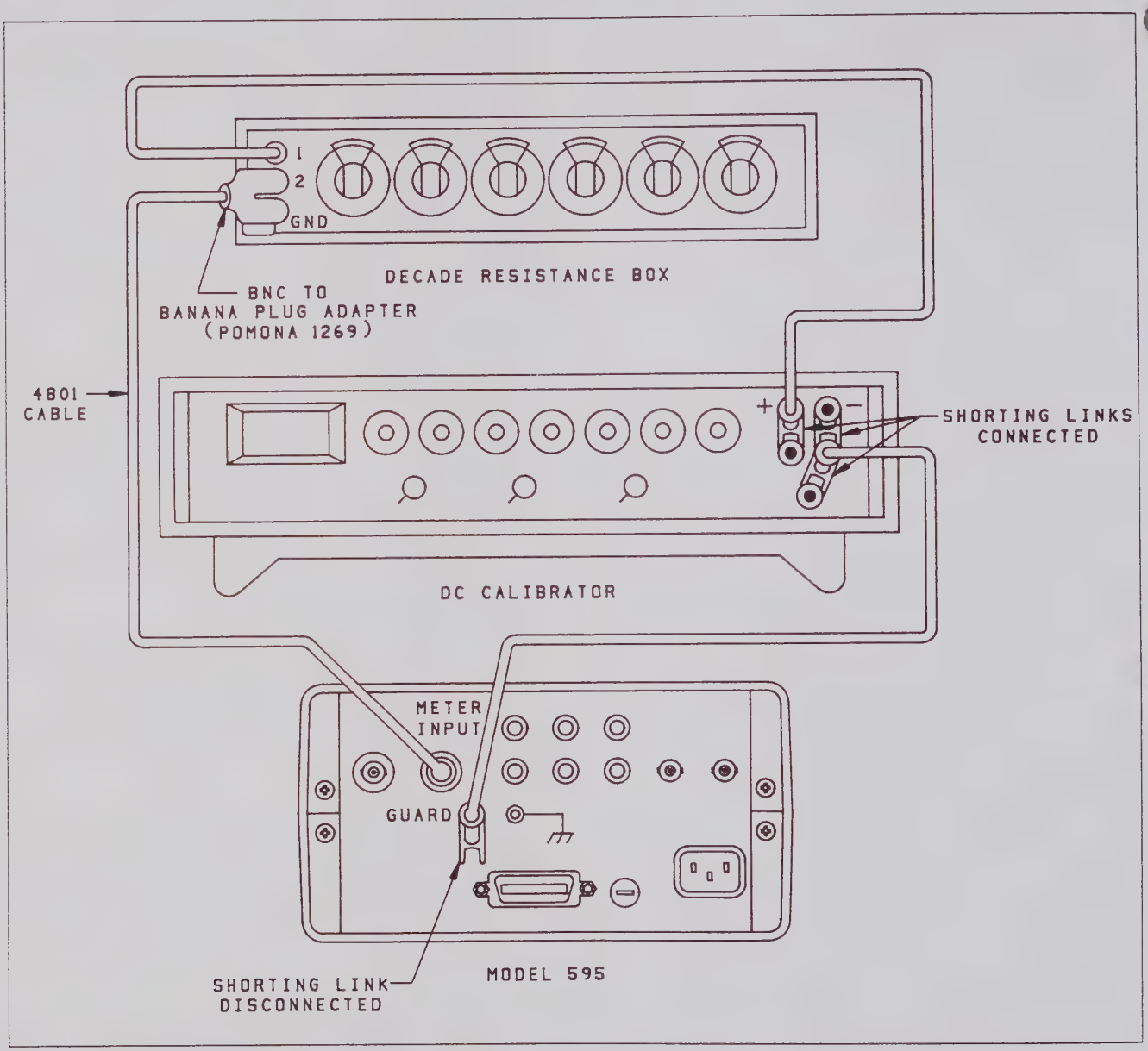


Figure 8-7. Current Calibration Setup (20μA to 200μA Ranges)

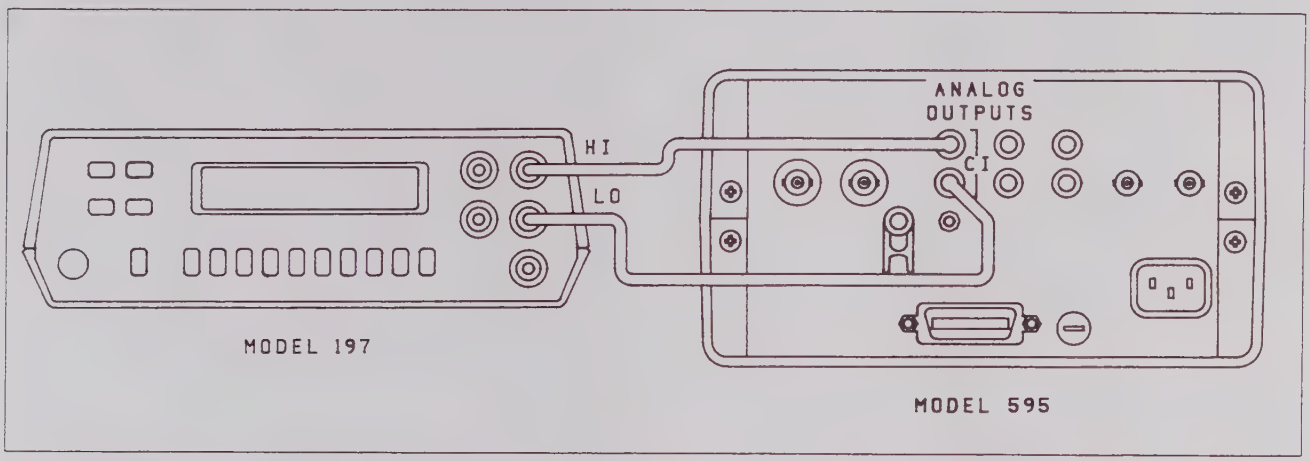


Figure 8-8. C, I Analog Output Calibration Setup

8.5.15 I,C Analog Output Adjustment

Calibrate the I,C Analog Output as follows:

1. Select the current function, 200μA range, filter 2 and enable ZERO CHECK.
2. Connect the current source to the input as shown in Figure 8-7. Set the decade resistance box to 100kΩ and set the calibrator to output 0V.
3. Using the DMM, monitor C,I ANALOG OUTPUT at the rear panel of the Model 595 as shown in Figure 8-8. Verify that the offset voltage is less than 2mV.
4. Disable ZERO CHECK, allow the reading to settle, and then enable SUPPRESS.
5. Apply 190μA to the input by setting the calibrator to output 19V and adjust R333 (see Figure 8-2) for a DMM reading of 1.9000V ±100μV.

8.5.16 Q/t Calibration

Like current calibration, Q/t digital calibration requires a 190pA source applied to the input of the Model 595. Paragraph 8.5.14 explains how to configure the necessary equipment for the 190pA source.

Calibrate Q/t as follows:

1. Select the capacitance function, 2nF range, 1 second delay time, and 0.1V squarewave step.
2. Select the Q/t display.
3. Make sure the calibration program is selected if calibration is to be done from the front panel.
4. Verify that with a capped input the display reads .0000 nA ±2 counts.
5. Connect the current source to the Model 595 as shown in Figure 8-6. Note that the 10GΩ resistor must be installed in the test fixture.
6. Set the DC calibrator to the voltage listed in the first line of Table 8-3.
7. For front panel calibration, adjust the display to read .1900 n.A.. Note that the decimal points in the displayed exponent indicate that the calibration program is selected. For IEEE-488 bus calibration, send A190E-12X.

Q/t calibration is now stored in temporary memory. If it is desired to store the calibration constant in permanent memory at this time, perform the procedure in paragraph 8.5.18.

8.5.17 Capacitance Calibration

Capactitance digital calibration consists of connecting capacitors with known measured values to the input and digitally entering those values from the front panel or over the bus. The Model 5955 is a set of characterized (measured) capacitors that can be used to calibrate the Model 595. Before using the capacitors, make sure that the date for re-characterization has not passed. The characterization procedure for the Model 5955 is contained in its instruction manual.

Table 8-5. Capacitance Calibration

Range	Filter	Step V	Delay	Capacitance Value*
20nF	2	00.10 SQ	00.20 S	(18nF) _____
200pF	3	00.10 SQ	00.20 S	(180pF) _____
200pF	3	00.01 SQ	00.20 S	(180pF) "
2nF	2	00.10 SQ	00.20 S	(1.8nF) _____
2nF	2	00.05 SQ	00.20 S	(1.8nF) "
2nF	2	00.02 SQ	00.20 S	(1.8nF) "
2nF	2	00.01 SQ	00.20 S	(1.8nF) "

*Values in parenthesis are nominal values. Actual 1kHz values are recorded on the capacitors.

Perform the following procedure to calibrate capacitance:

1. Record the 1kHz values of the characterized capacitors in Table 8-5. The charcterized values are located on the capacitors.
2. Select the 20nF range, filter 2, 0.1V squarewave step, and a delay of 0.2 seconds. This setup data is listed in the first entry of Table 8-5.
3. Place the protection cap on the METER INPUT connector and make sure the calibration program is selected if calibration is to be done from the front panel.
4. Disable ZERO CHECK, wait 15 seconds and enable SUPPRESS in that order.
5. Remove the protection cap and connect the 18nF (nominal) capacitor to the input.
6. For front panel calibration, adjust the display to the capacitance value recorded in the first line of Table 8-5. For IEEE-488 bus calibration, send the recorded (characterized) value using the A command. For example, if the characterized value is 18.036nF, send A18.036E-9X over the bus.
7. Disable SUPPRESS and enable ZERO CHECK.
8. Repeat steps 2 through 7 for the remaining entries in Table 8-5. Each table entry defines the instrument setup (range, filter, step V, delay and input value). Note that calibration must be performed in the order presented in the table.

8.5.18 Storage of Calibration Parameters

The digital calibration procedures given in the preceding paragraphs temporarily store calibration constants in internal RAM (Random Access Memory). For calibration to be permanent, you must perform permanent storage into NVRAM (Non-volatile Random Access Memory).

NOTE

Storage will only occur if a change to digital calibration has occured. Also, the calibration program must be selected to perform storage from the front panel.

Front Panel NVRAM Storage - To store calibration constants into permanent memory, press the MENU button. The following message will be displayed momentarily:

Stor

The instrument wil' then exit from the calibration program.

IEEE-488 Bus NVRAM Storage - If storage is to be done from over the IEEE-488 bus, simply send the following command:

J19X

Note that these storage procedures need be performed only once after all calibration parameters have been entered. Keep in mind that the calibration jumper must be in the correct position, as described in paragraph 8.5.4.

If storage is aborted because the calibration jumper is in the disable position, the exponent decimal points will blink to indicate that permanent storage did not occur. Storage can still be accomplished as follows:

1. Place the calibration jumper to the enable position (see paragraph 8.5.4).
2. Select the calibration program from the program menu (exponent decimal points displayed, but not blinking).

3. Press the ▲ button to increment the reading by one count and then press the ▼ button to decrement the reading by one count. Pressing an ADJUST button tells the instrument that a calibration adjustment has occured.
4. Press the MENU button and the "Stor" message will then be dislayed.

Note: If an ADJUST button is not pressed in step 3, storage will not occur in step 4. Instead, the MENU button will scroll the program menu.

8.5.19 Additional Calibration Points

The meter calibration points discussed in the preceding paragraphs were chosen to optimize instrument accuracy without making the calibration procedure overly tedious and time consuming. As noted earlier, these calibration points are permanently stored when the correct storage sequence is performed. Other calibration points are derived from the stored values in normal use during power up, "Stor", and device clear (DCL and SDC).

Although this calibration method is more than adequate to allow the instrument to meet specifications, it should be pointed out that it is possible to temporarily calibrate those ranges not directly calibrated as part of the calibration procedure. To temporarily calibrate additional ranges, proceed as follows:

1. With the calibration jumper in the disabled position (see paragraph 8.5.4), place the instrument in the desired function and select the range to be calibrated.
2. Apply the necessary calibration signal and enter that value into the instrument's memory, either with the front panel calibration program, or over the IEEE-488 bus. (The flashing exponent decimal points indicate parameters have been entered.)

The nominal adjustment range is ±6%. However, it is important to note that such calibration will be only temporary as these parameters will be lost when the power is turned off. Under these conditions, the instrument will revert to calibration constants previously stored in permanent memory the next time it is turned on. Note that the IEEE-488 DCL and SDC commands will also cancel temporary calibration constants.

As an example of this procedure, let us assume that you wish to temporarily calibrate the 2nA range -- a range that is not part of the normal calibration sequence. The following basic procedure could be used to calibrate this range. Remember that the calibration jumper must be in the disable position.

1. Select the calibration program if the calibration constant is to be entered from the front panel.
2. Set the instrument to the 2nA range.
3. Zero correct the instrument by enabling ZERO CHECK and then CORRect in that order.
4. Apply 0nA to the input, disable ZERO CHECK and enable SUPPRESS in that order.
5. Connect a suitable calibration signal to the instrument. Typically, calibration is done at 95% of full range, or 1.9nA in this case.
6. For front panel calibration, use the voltage source ADJUST buttons to set the displayed value to 1.9000 nA and press the MENU button. The "out" message will be displayed briefly. For IEEE calibration, send A1.9E-9X over the bus. The flashing exponent decimal points indicate that calibration is temporary.

8.6 DISASSEMBLY INSTRUCTION

If it is necessary to troubleshoot the instrument or replace a component, use the following disassembly procedure. An exploded view of the instrument may be found in Figure 8-9.

WARNING

Disconnect the line cord and any cables from the instrument before disassembly.

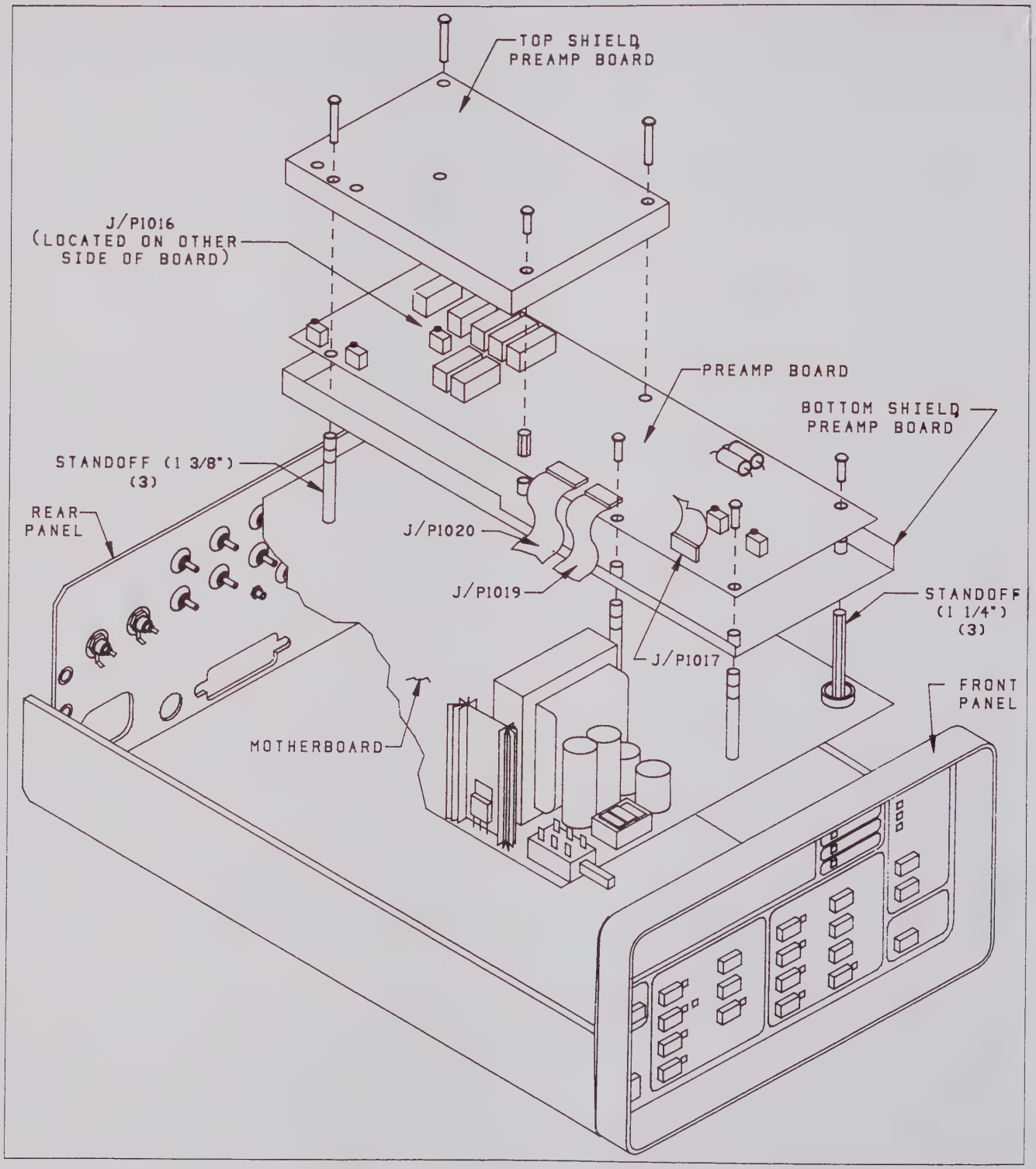


Figure 8-9. Model 595 Exploded View

1. Remove the top cover as follows:
   A. Remove the two screws that secure the top cover to the rear panel.
   B. Grasp the top cover at the rear and carefully pull up until the tabs at the front of the cover clear the front panel. The cover may then be pulled completely clear.
   C. To replace the top cover, reverse the above procedure. Be sure to install the tabs at the front of the cover before completely installing it.
2. Remove the preamp board as follows:
   A. Disconnect P1019 and P1020 from the mother board, and P1017 from the preamp board.
   B. Remove the six screws that secure the preamp board to the six standoffs.
   C. Disconnect P1016 from the bottom of the preamp board
   D. Carefully remove the preamp board, taking care not to touch the PC board surfaces or any components.
   E. To remove the preamp board shield, remove the one remaining screw securing it to the board.
3. Remove the mother board as follows:
   A. Disconnect the display board ribbon cable from the mother board.
   B. Remove the three standoffs located along the edge of the board, and the three additional screws that secure the mother board to the bottom case. Do not remove the three standoffs located down the center of the board.
   C. Remove the two screws that secure the rear panel to the bottom case and remove the mother board and rear panel as a single unit.
4. The display board can now be removed as follows:
   A. Remove the two screws securing the display board to the front panel.
   B. Remove the display board by lifting up and back until the tabs at the bottom of the case are clear and then lift the display board free.
5. The instrument can be re-assembled by reversing the above procedure. Make sure that all boards are properly seated and secured, and that all connections are properly made. To ensure proper operation, shields must be replaced and fastened securely.

WARNING

To ensure continued protection against safety hazards, power line ground (the green wire connected to the ac power receptacle) must be connected to the rear panel and mother board.

8.7 SPECIAL HANDLING OF STATIC SENSITIVE DEVICES

CMOS devices operate at very high impedance levels for low power consumption. As a result, any static charge that builds up on your person or clothing may be sufficient to destroy these devices, if they are not handled properly. Use the precautions below to avoid damaging them.

NOTE

Since the many CMOS devices installed in the Model 595 are not denoted in this manual, all ICs and transistors should be handled as static sensitive devices.

1. ICs should be transported and handled only in containers specially designed to prevent static build-up. Typically, these parts will be received in anti-static containers of plastic or foam. Keep these devices in their original containers until ready for installation.
2. Remove the devices from their protective containers only at a properly grounded work station. Also ground yourself with a suitable wrist strap.
3. Handle the devices only by the body; do not touch the pins.
4. Any printed circuit board into which the device is to be inserted must also be grounded to the bench or table.
5. Use only anti-static type solder sucker.
6. Use only grounded tip soldering irons.
7. Once the device is installed on the PC board, it is normally adequately protected, and normal handling can resume.

8.8 TROUBLESHOOTING

The troubleshooting information contained in this section is intended for qualified personnel having a basic understanding of analog and digital circuitry. The individual should also be experienced at using typical test equipment, as well as ordinary troubleshooting procedures. The information presented here has been written to assist in isolating a defective circuit or circuit section. Isolation of the specific component is left to the technician. Note that schematic diagrams and component layout drawings, which are an essential aid in troubleshooting, are located at the end of Section 9.

Table 8-6. Recommended Troubleshooting Equipment

Equipment	Use
DMM with 0.015% basic DC accuracy, 10MΩ input impedance (Keithley Model 197 or equivalent).	Power supply and DC voltage checks; analog signal tracing; continuity; static logic levels.
Storage oscilloscope, DC-50MHz bandwidth.	Digital and analog waveform checks.

8.8.1 Recommended Test Equipment

Success in troubleshooting complex equipment like the Model 595 depends not only on the skill of the technician, but also relies on the use of accurate, reliable test equipment. Table 8-6 lists the minimum recommended equipment for troubleshooting the the Model 595. Other equipment such as logic analyzers and capacitance meters could also be helpful, especially in difficult situations.

8.8.2 Power Up Self Test

Upon power up, the Model 595 will automatically test its RAM and ROM memory, and check for proper calibration constants. If a RAM error occurs, the following message will remain on the display:

r.r.

If a ROM error occurs, the following message will remain on the display:

r.o.

With either error, the instrument will be completely inoperative. If any of these errors occur, it should be assumed that a problem exists within the instrument. The problem should be rectified before using the instrument.

If a calibration error occurs, the two exponent decimal points will flash. The instrument will be functional under these conditions, but calibration is not accurate. Use the calibration procedures in paragraph 8-5 of this section to calibrate the instrument. Note that this error may also indicate a defective NVRAM (permanent memory).

8.8.3 Self Diagnostic Program

The self diagnostic program can be used to test the front panel indicator lights, access the software revision level, and enter a special mode to allow signal tracing through the instrument. Enter the diagnostic program as follows:

1. Turn off the instrument for at least three seconds if it is presently turned on.
2. Press and hold the C/C_0 button while turning on power.
3. The instrument will test RAM and ROM as it normally does on power-up, and then turn on all front panel indicator lights and display segments. The instrument will remain in this configuration as long as the C/C_0 button is held in.
4. The software revision level will be displayed when the C/C_0 button is released. A typical example is:

   A1

   Note that the revision level of your instrument may be different.
5. At this point, the instrument will enter the diagnostic mode that switches the instrument among the zero (common), calibration (reference), and signal phases of its measurement cycle. The unit can be cycled through these phases by repeatedly pressing the C/C_0 button. The decimal point will indicate the range. During the zero (common) phase, the display will appear as follows:

   P = 0

6. During the calibration (reference) phase, the display will show:

   P = C

7. Finally, the display will show the following message during the signal phase:

P = S

8. To remove the instrument from the diagnostic mode, turn off the power.

During normal operation, the instrument cycles through these three phases in rapid succession. This cycling action makes it difficult to troubleshoot the instrument utilizing normal signal-tracing techniques. However, by using the diagnostic program to "freeze" the instrument on the appropriate phase, troubleshooting is greatly simplified. Table 8-7 summarizes phases, display messages, and signals applied to the A/D converter during each of the three phases.

Table 8-7. Diagnostic Program Phases

Phase	Display Message	A/D Converter Input Signal (U129, pin 15)
Zero (Common)	P = 0	Analog Common
Calibration (Reference)	P = C	−2V Reference
Signal	P = S	Output of Preamplifier (X1) or X10 amplifier

8.8.4 Power Supply Checks

All power supply voltages should be checked first to make sure they are within the required limits. If the various operating voltages are not within the required limits, troubleshooting the remaining circuitry can be quite difficult.

Table 8-8 outlines the various power supply voltages that should be checked. In addition to the usual voltage checks, it is a good idea to check the various supplies with an oscilloscope to make sure that no noise or ringing is present.

8.8.5 A/D Converter Checks

Use the procedure listed in Table 8-9 to make sure the A/D converter is operating properly. The operation of the A/D converter should be verified before attempting to troubleshoot the analog circuitry.

8.8.6 Voltage Source Checks

Check out the operation of the voltage source by using the procedure in Table 8-10. The first 10 steps in the table check the voltage source circuitry, while the remaining steps check out the step voltage circuitry. Note that the power supply voltage should be checked first to ensure proper operation of the voltage source.

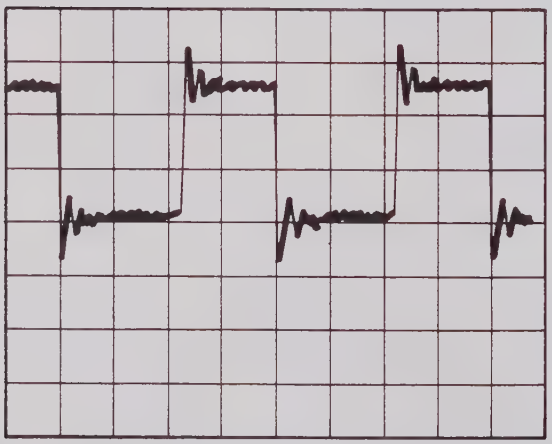
Table 8-8. Power Supply Checks

Step	Item/Component	Required Condition	Remarks
1	S102	Set to 115 or 230 as required	Line voltage selection
2	F101	Check for continuity	Remove fuse and measure resistance (≈25Ω for FU-20, ≈85Ω for FU-21).
3	Line Power	Connect line power & turn on	
4	±24V supplies	±27.5V ±13%	Referenced to ±24V common
5	±15V supplies	+15V, −15V, ±10%	Referenced to analog common
6	+9D supply	+9V ±16%	Reference to digital common
7	+5D supply	+5V ±5%	Referenced to digital common

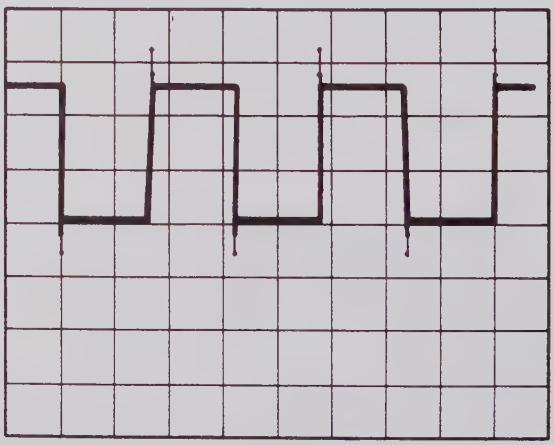
Table 8-9. A/D Converter Checks*

Step	Item/Component	Oscilloscope Settings	Required Condition	Remarks
1	U125, pin 10	2V/div, 0.2μs/div	Waveform 1	A/D Clock (1.2288MHz)
2	U125, pin 9	2V/div, 0.5μs/div	Waveform 2	614.4kHz clock
3	U125, pin 7	2V/div, 1μs/div	Waveform 2	307.2kHz clock
4	U25, pin 6	2V/div, 2μs/div	Waveform 2	153.6kHz clock
5	U125, pin 5	2V/div, 5μs/div	Waveform 3	76.8kHz clock
6	U125, pin 3	2V/div, 10μs/div	Waveform 3	38.4kHz clock
7	U125, pin 1	2V/div, 1ms/div	Waveform 4	300Hz clock
8	U136, pin 6	2V/div, 5μs/div	Waveform 5	Change balance synchronization signal ($^1/_8$ duty cycle)
9	U132, pin 6	2V/div, 5ms/div	Waveform 6**	Integration output
10	U137, pin 6	2V/div	+5V DC	Charge balance reference
11	U137, pin 7	2V/div, 10ms/div	Waveform 7**	Charge balance output
12	U124, pin 6	2V/div, 10ms/div	Waveform 7**	Charge balance current generator
13	U136, pin 8	2V/div, 10ms/div	Waveform 8**	A/D Data Output
14	U135, pin 10	2V/div, 10ms/div	Waveform 9	Control line for single slope enable
15	U124, pin 9	2V/div, 10ms/div	Waveform 10	Input Enable

*Model 595 in power up default state. Voltages referenced to GUARD.
**Specific shape depends on A/D phase.



WAVEFORM 1



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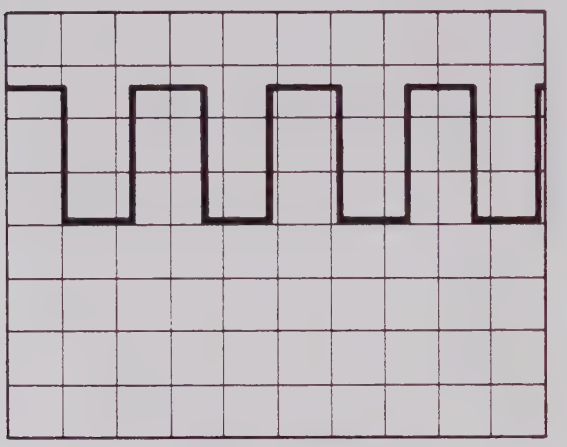

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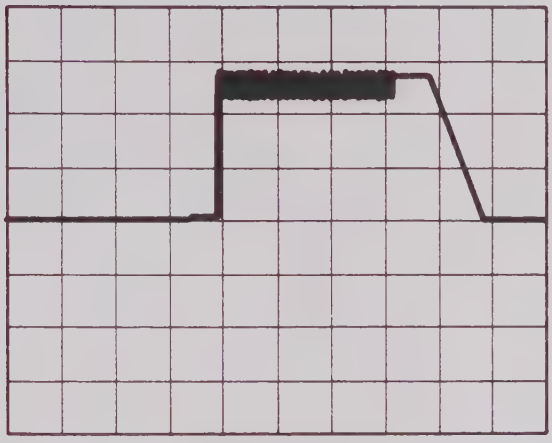
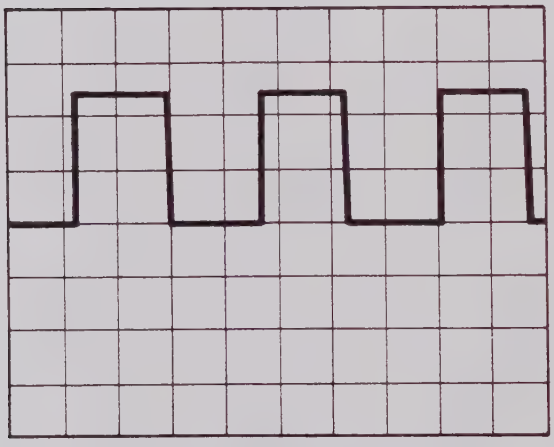
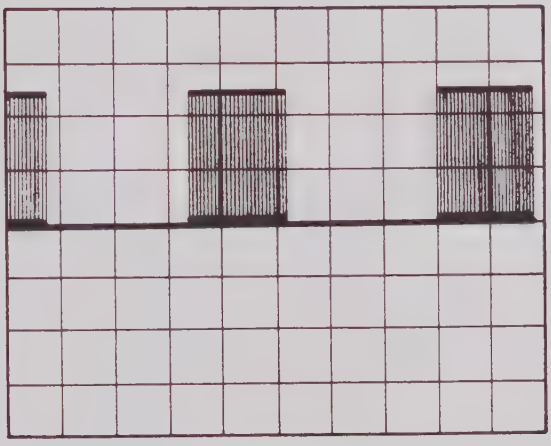


WAVEFORM 6



WAVEFORM 4



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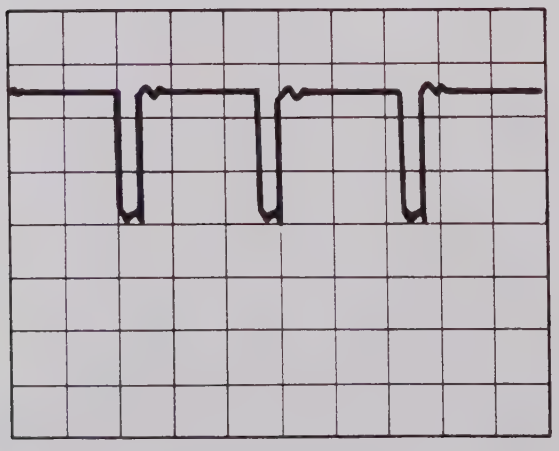

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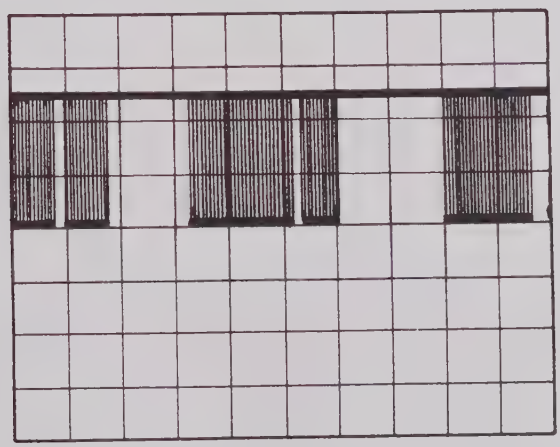

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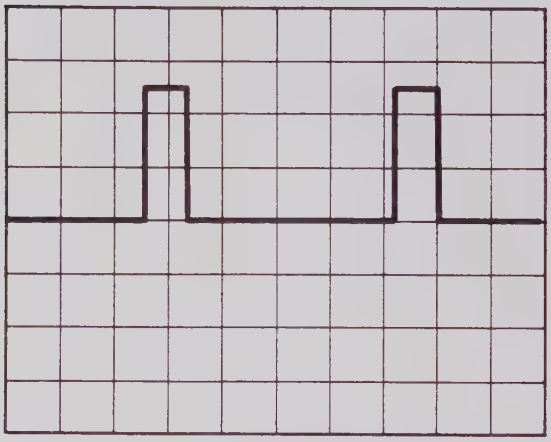
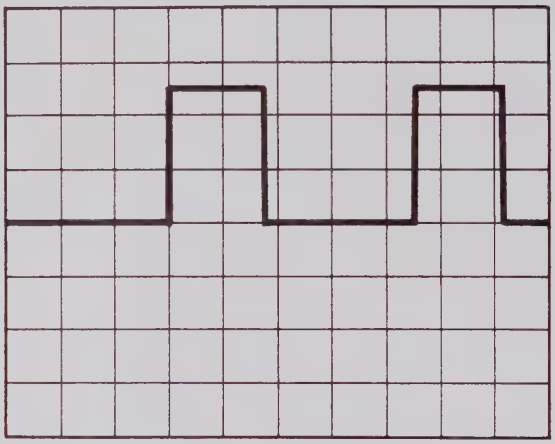


WAVEFORM 9



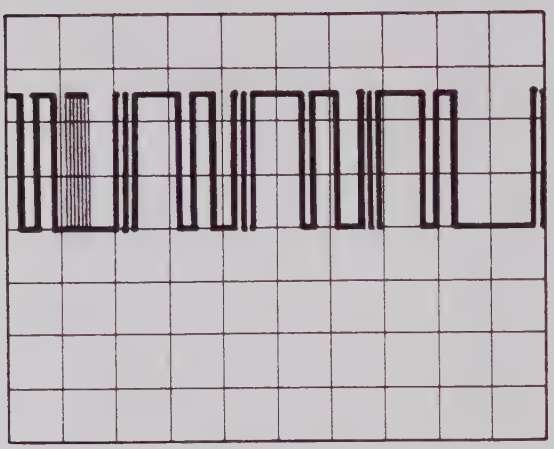
WAVEFORM 10

Table 8-10. Voltage Source Checks*

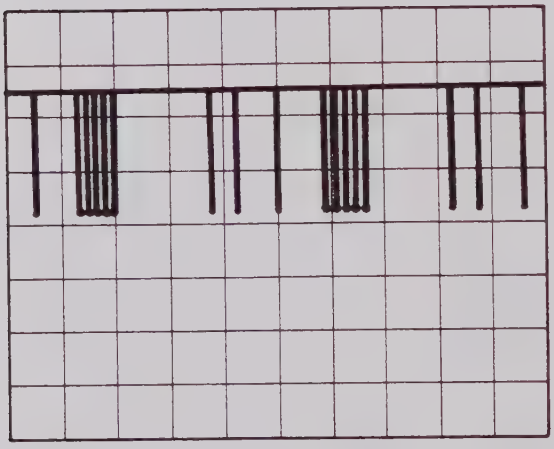
Step	595 Setup	Scope Settings	Item/Component	Required Condition	Remarks
1	A	2V/div, 20ms/div	U139, pin 7	Waveform 11	DATA input (serial)
2	A	2V/div, 10ms/div	U139, pin 4	Waveform 12	CLOCK data into latches of U139
3	A	2V/div, 20ms/div	U139, pin 9	Waveform 13	STROBE - pass data to D/A
4	A	**	U134, pin 3	6.35V ±0.1V	Zener voltage (VR101)
5	A	**	U139, pin 15	10.24V***	Reference V
6	A	**	U140, pin 7	−9.5V	Convert I output to V
7	A	**	U141, pin 6	−0.2V ±0.1V	Output of op amp
8	A	**	T103, pin 1	19.00V ±0.05V	Output of −X2 amp
9	A	**	VOLTAGE SOURCE OUTPUT	19.00V ±0.05V	Voltage at BNC output connector
10	B	**	U130, pins 10 and 11	5V	STEP A and STEP B input to mux
11	B	2V/div, 50ms/div	U130, pin 9	Waveform 14	STEP C input to mux
12	B	50mV/div, 50ms/div	U123, pin 6	Waveform 15	Step voltage input to mux
13	B	50mV/div, 50ms/div	VOLTAGE SOURCE OUTPUT	Waveform 15	Step voltage at output

SETUP A: 19.00V, DC output, capacitance function, ZERO CHECK enabled
SETUP B: 0.1V SQ step, 0V, STEP output, 0.07sec delay time

*All voltages referenced to GUARD.
**Preferable to use DMM for DC voltage measurements.
***Exact value set during calibration.



WAVEFORM 11



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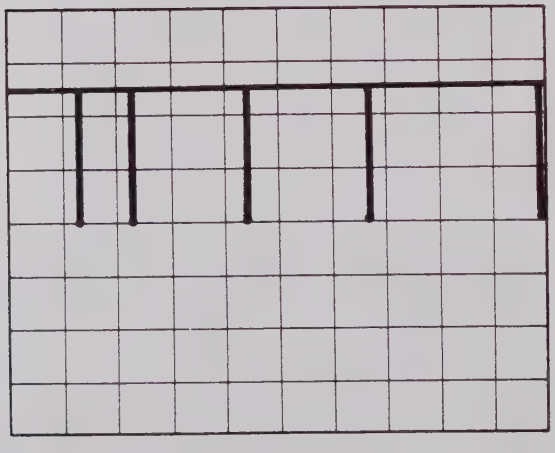

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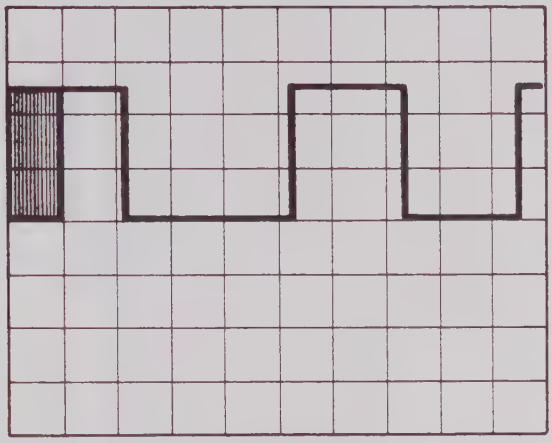

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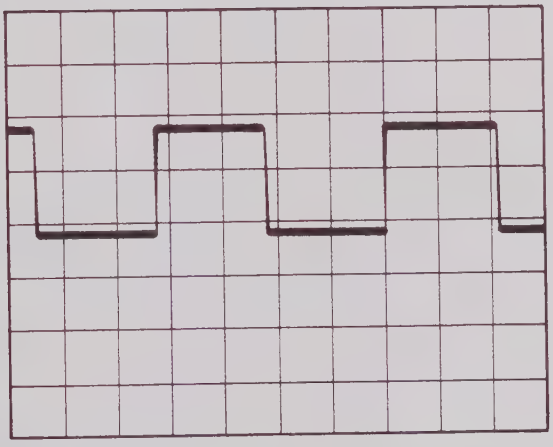


WAVEFORM 15

Table 8-11. Relay Configuration

Function	Range	Relay						
		K301	K302	K303	K304	K305	K306	K307
Capacitance	200pF							
	2nF					X		
	20nF			X				
	Current	20pA					X	
	200pA						X	
	2nA				X	X		
	20nA				X	X		
	200nA		X	X				
	2μA		X	X				
	20μA			X				X
	200μA			X				X
	Zero Check	X	*	*	*	*	*	*

X = Realy energized.

* = These relays may also be energized depending on range and function.

8.8.7 Relay Configuration

Instrument functions are controlled by configuring the input amplifier with a number of relays. These relays are themselves controlled by serial-parallel converter ICs that decode control information from the microprocessor. Since each relay must assume a given state for proper operation, it is possible to verify input configuration switching by determining which relays are energized for every range and function.

Table 8-11 gives a summary of status for each of the seven relays associated with the input section. You can verify proper relay operation for a given combination by selecting the range and function in question and then measuring the control voltage at the IC driver output. When a relay is energized (on), the voltage at the output will be high, while approximately 0V will be seen with the relay de-energized (off), except K307 which is energized when driven with 0V, and de-energized when driven to +5V.

8.8.8 Input Conditioning Circuitry Checks

The input and X10 amplifiers condition the input signal, transforming it into a 0-2V dc voltage that is usable by the A/D converter. The exact conditioning process will depend on the selected range and function. For the current function, the input signal must undergo current-voltage conversion. For the capacitance function, the input signal must undergo charge to voltage conversion.

Table 8-12 lists the gains selected by the multiplexer (U129) for the various functions and ranges.

The procedures outlined in Tables 8-13 and 8-14 may be used as an aid in troubleshooting the input conditioning circuitry.

8.8.9 Digital Circuitry

Problems with the digital circuitry could cause erratic operation. Check the various components associated with the digital circuitry using the procedure given in Table 8-15.

Table 8-12. Amplifier Gains

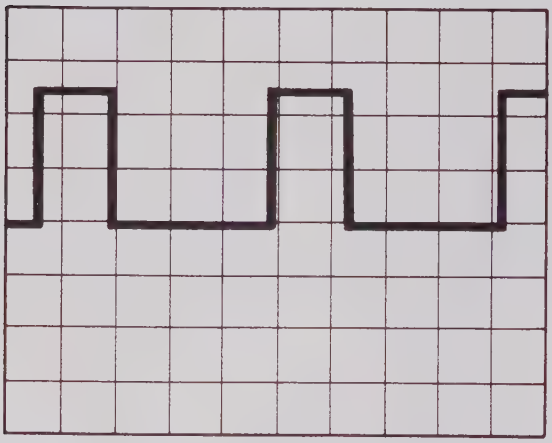
Function	Range	Gain	Voltage at TP1 for Full Scale Input
Capacitance	200pF	X1	2V Squarewave
	*	X10	0.2V Squarewave
	2nF	X1	2V Square Wave
	20nF	X1	2V Squarewave
Current	20pA	X10	0.2V DC
	200pA	X1	2V DC
	2nA	X10	0.2V DC
	20nA	X1	2V DC
	200nA	X10	0.2V DC
	2μA	X1	2V DC
	20μA	X10	0.2V DC
	200μA	X1	2V DC

*0.01V step on any range; for all others, step voltage is 0.10V

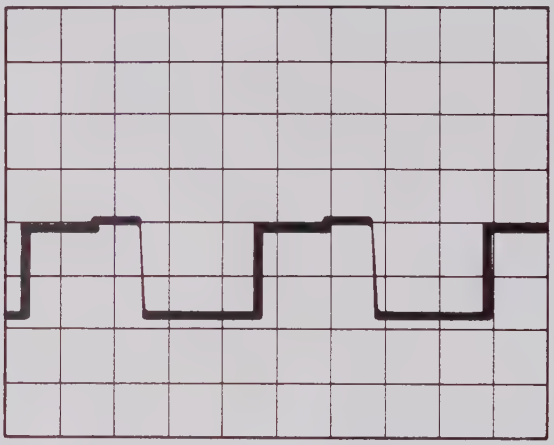
Table 8-13. Capacitance Circuitry Checks

	595 Settings*		Applied	Scope	Item/Component				
Step	Range	Step V	Input	Settings	U302 pin 11	U305, pin 6 (TP1)	U304 pin 10	U131 pins 3 & 6	Remarks
1	—	—	—	2V/div, 50ms/div	Waveform 16	—	—	—	Discharge drive
2	20nF	00.10 SQ	10nF	0.5V/div, 50ms/div	—	Waveform 17	—	—	Preamp output
3	20nF	00.10 SQ	10nF	1V/div, .1s/div	—	—	—	Waveform 18	A/D input
4	2nF	00.10 SQ	1nF	0.5V/div, 50ms/div	—	Waveform 17	—	—	Preamp output
5	2nF	00.10 SQ	1nF	1V/div, .1s/div	—	—	—	Waveform 18	A/D input
6	200pF	00.10 SQ	100pF	0.5V/div, 50ms/div	—	Waveform 19	—	—	Preamp output
7	200pF	00.10 SQ	100pF	1V/div, .1s/div	—	—	—	Waveform 18	A/D input
8	200pF	00.01 SQ	100pF	50mV/div, .1s/div	—	Waveform 20	—	—	Preamp output
9	200pF	00.01 SQ	100pF	0.5V/div, .1s/div	—	—	Waveform 20	—	X10 amp output
10	200pF	00.01 SQ	100pF	1V/div, .1s/div	—	—	—	Waveform 21	A/D input

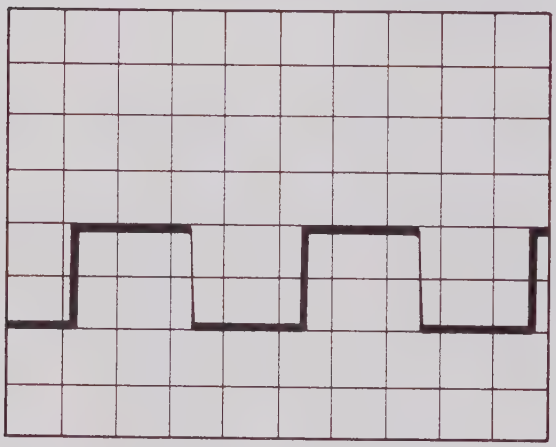
*Delay time of 00.07sec (default), STEP waveform selected, preamplifier board shield must be fastened in place.



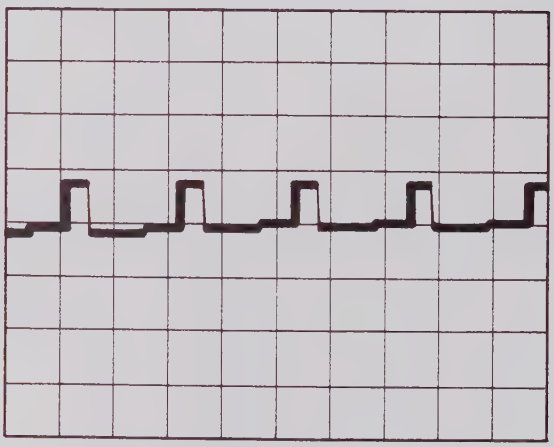
WAVEFORM 16



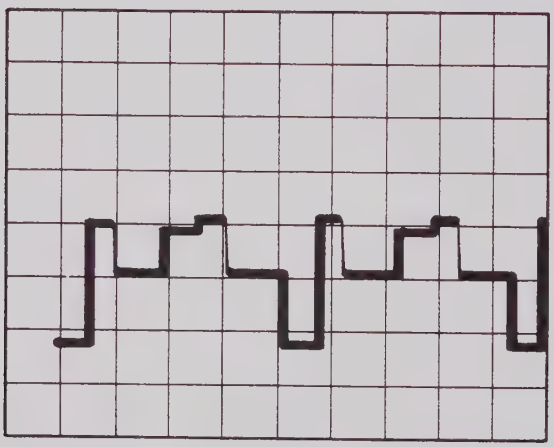
WAVEFORM 19



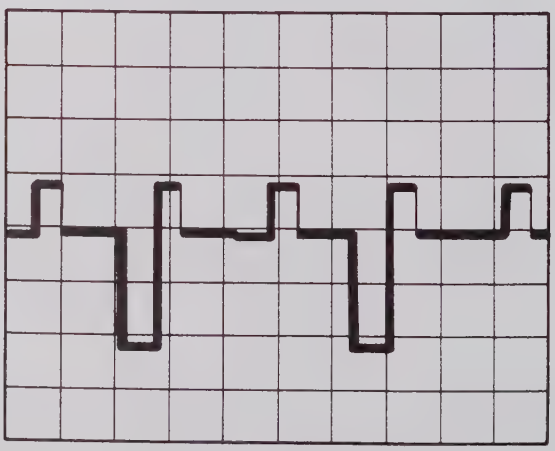
WAVEFORM 17



WAVEFORM 20



WAVEFORM 18



WAVEFORM 21

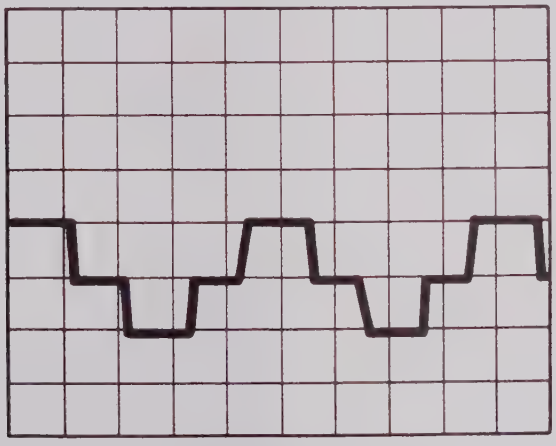
Table 8-14. Current Circuitry Checks

Step	Range*	Applied Input	Item/Component			
			U305, pin 6 (TP1)	U304, pin 10	U129, pin 1	U131 pins 3 and 6**
1	20pA	10pA	−100mV	−1V	−1V	See waveform 22
2	200pA	100pA	− 1 V	—	−1V	See waveform 22
3	2nA	1nA	−100mV	−1V	−1V	See waveform 22
4	20nA	10nA	− 1 V	—	−1V	See waveform 22
5	200nA	100nA	−100mV	−1V	−1V	See waveform 22
6	2 μA	1 μA	− 1 V	—	−1V	See waveform 22
7	20 μA	10 μA	−100mV	−1V	−1V	See waveform 22
8	200 μA	100 μA	− 1 V	—	−1V	See waveform 22

*Model 595 set for 0.07 second delay and 0.1V step.
**Use scope set for 1V/div and 50ms/div

Notes:

1. TP1 is the output of the preamplifier
2. U304 pin 10 is the output of the X10 amplifier
3. U129, pin 1 is the signal input to the multiplexer
4. Signal at pins 3 and 6 of U131 is the input to the A/D converter.

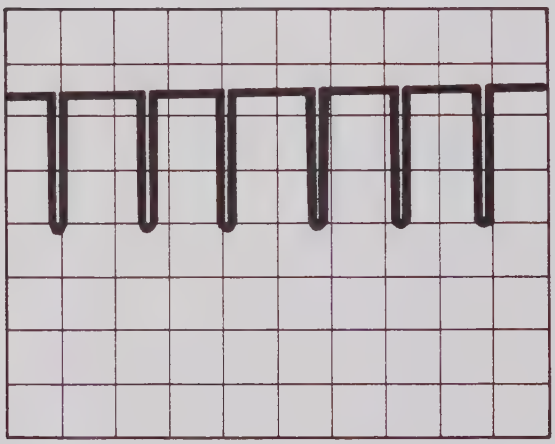


WAVEFORM 22

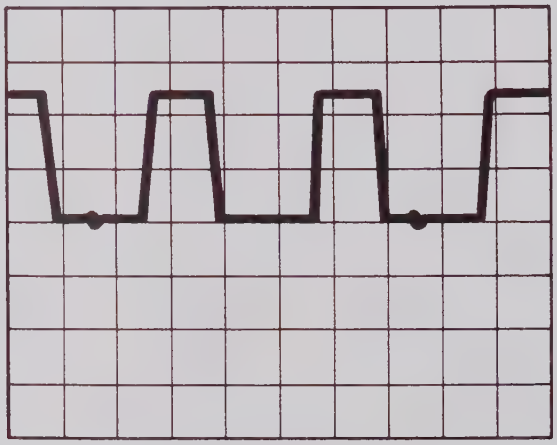
Table 8-15. Digital Circuitry Checks*

Step	Item/ Component	Oscilloscope Settings	Required Condition	Remarks
1	U109, pin 40	2V/div	+5V ±5%	+5V digital supply
2	U109, pin 2	2V/div, 1ms/div	Waveform 23	Interrupt clock
3	U109, pin 1	2V/div	Stays low <1 sec on power-up, then goes high (≈5V)	MPU reset
4	U109, pin 4	2V/div, 0.5μs/div	Waveform 24	Data strobe
5	U109, pin 6	2V/div, 0.5μs/div	Waveform 25	Address strobe
6	U109, pin 37	2V/div, 50ms/div	Waveform 26	A/D Data
7	U102, pin 6	2V/div, 20ms/div	Waveform 27	A/D control
8	U102, pin 8	2V/div, 20μ/div	Waveform 28	Voltage supply control
9	U102, pin 3	2V/div, 50ms/div	Waveform 29	Meter complete

*Power-up default state. Voltages referenced to digital common.

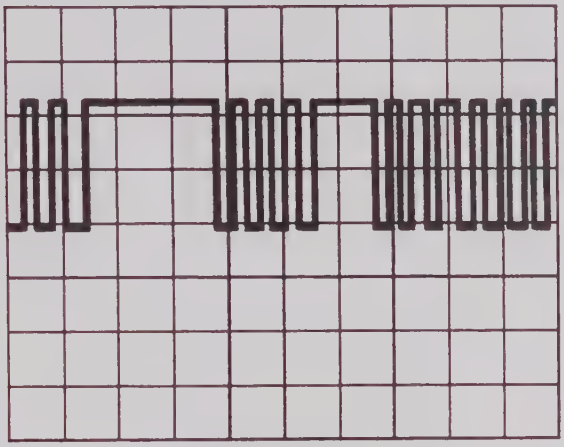


WAVEFORM 23

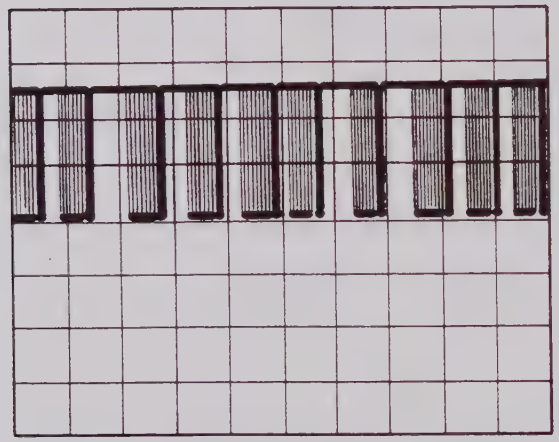


WAVEFORM 24

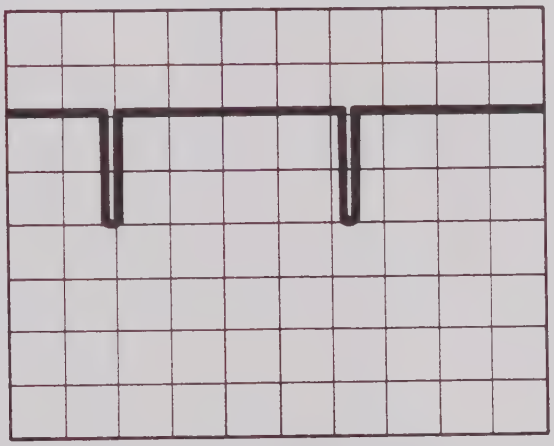
WAVEFORM 25



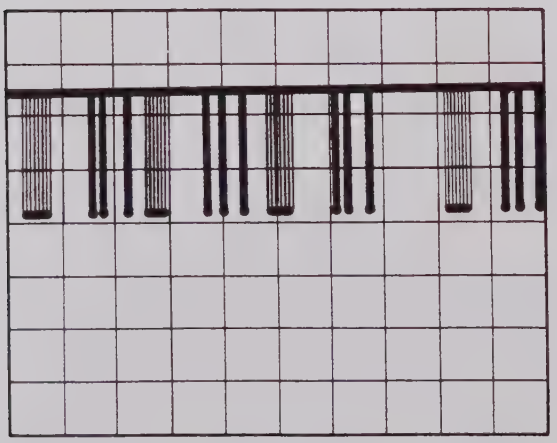
WAVEFORM 28



WAVEFORM 26



WAVEFORM 29



WAVEFORM 27

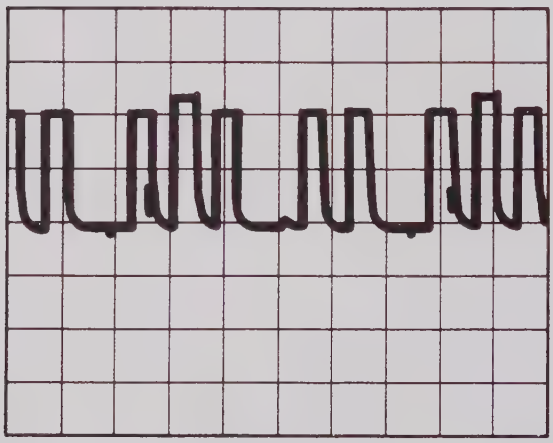
Table 8-16. Display Circuitry Checks*

Step	Item/Component	Oscilloscope Settings	Required Condition	Remarks
1	U201, pin 9	2V/div	+5V ±5%	+5V supply
2	U201, U202, pins 11-18	2V/div, 2ms/div	Waveform 30	Segment drivers
3	U204, pins 11-18 U205, pins 15-18	2V/div, 2ms/div	Waveform 31	Digit drivers
4	U203, pins 10-15	2V/div, 2ms/div	Waveform 32	Digit Multiplexer
5	P1021, pin 14	2V/div, 2ms/div	Depress SUPPRESS, RANGE ▼, ▲ LIMIT, DELAY TIME, +/– or SELECT ▼ button and observe Waveform 33	Pulse present when button pressed.
6	P1021, pin 15	2V/div, 2ms/div	Depress C/C_O, RANGE ▲, SHIFT STEP V, ADJUST ▼ or SELECT ▲ buttonand observe Waveform 33	Pulse present when button pressed.
7	P1021, pin 16	2V/div, 2ms/div	Depress CURRENT, CAPACITANCE, ZERO CHECK, ▼ LIMIT, ADJUST ▲, DISPLAY SOURCE or MENU button and observe Waveform 33	Pulse present when button pressed.

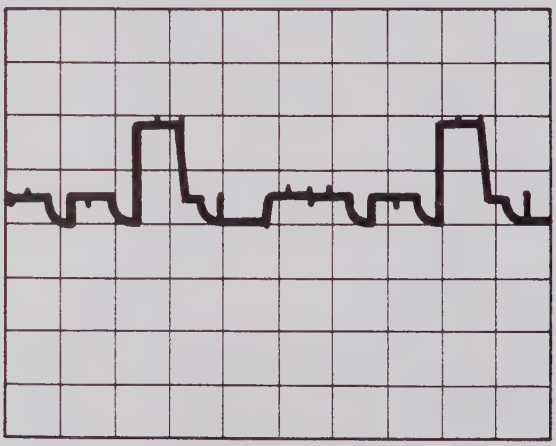
*Power-up default state. Voltages referenced to digital common.

8.8.10 Display Board Checks

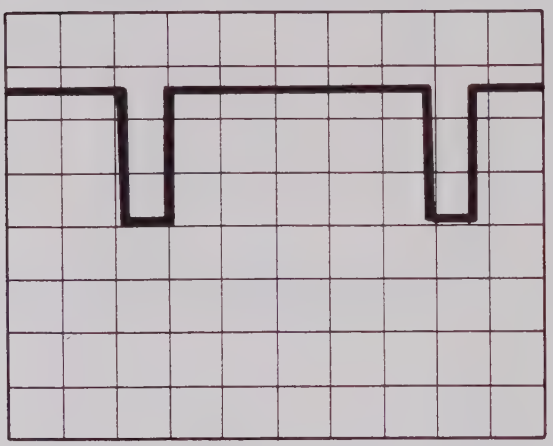
Check out the display board by using the procedure in Table 8-16.



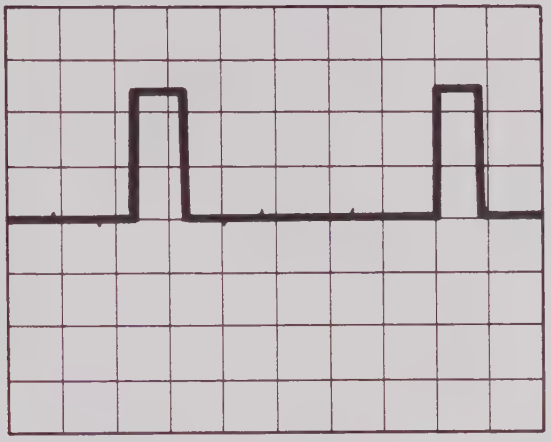
WAVEFORM 30



WAVEFORM 31



WAVEFORM 32



WAVEFORM 33

8.9 INPUT STAGE BALANCING PROCEDURE

If the input FET (Q302) or associated bias resistors are replaced, the following procedure should be used to rebalance the circuit. This procedure may also be used if the offset adjustment potentiometer R315 has insufficient range. The procedure involves checking the number of counts of offset with jumper W301 in position B.

Referring to Figure 8-10, proceed as follows:

1. Turn on the power and allow the instrument to warm up for one hour.

NOTE

Steps 2 through 9 should be comleted within ≈5 minutes to maintain the proper internal temperature.

2. Remove the top cover and preamp board shield.
3. Place jumper W301 in position B.
4. Enable ZERO CHECK.
5. Set the input offset adjustment potentiometer R315 fully clockwise. The control is a 15-turn potentiometer, so considerable adjustment may be required.
6. Note the number of counts shown on the display and compare the value to the ranges listed in Table 8-17. From this table, you can determine which position jumper W301 should be placed in. For example, if the display shows between −1200 and +200 counts, jumper W301 should be placed in position C.
7. Place the jumper in the position determined in step 5.
8. Replace the preamp board shield.
9. On the 20pA range, with ZERO CHECK still enabled, set the input offset potentiometer R315 for a reading of 0.000 pA ±1 count on the display.
10. Replace the top cover when the procedure is complete.
11. After the instrument is again allowed to warm up, check that the display reading is still 0.000pA ±1 count.

8.10 HANDLING AND CLEANING PRECAUTIONS

When troubleshooting or otherwise working inside the instrument, care should be taken not to indiscriminately touch PC board traces and open wires to avoid contaminating them with body oils or other foreign matter. In particular, there are two areas within the Model 595 that have numerous high impedance nodes where contamination could cause degraded performance. These include the input and X10 amplifier area on the preamp board.

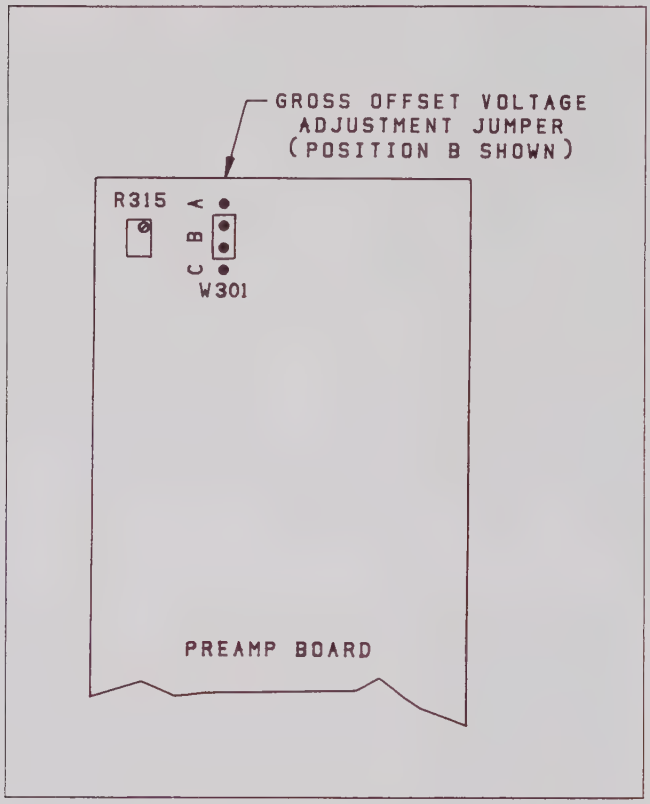


Figure 8-10. Input Stage Balancing

Table 8-17. Input Stage Balancing

Display Count	W303 Position
1400 to 2800	A
200 to 1400	B
−1200 to 200	C

The same general precautions apply when replacing parts in these areas. When unsoldering and soldering parts, be careful not to spread the flux around the board to adjacent areas.

1. Using a squeeze bottle, carefully apply clean, uncontaminated methanol to the area to be cleaned. Use sufficient solution to thoroughly wet the circuit board.
2. Using a small, clean brush, wipe the area thoroughly until it is free of flux or contaminants. In some cases, it may be helpful to tilt the board at an angle and brush contaminants away from the affected area, allowing contaminated residue and methanol to run off the board.
3. Wash the area again with fresh, clean methanol, allowing it to drain, flushing contaminants off the board.
4. Once the area is thoroughly cleaned, it should be dried with pressurized dry clean air or nitrogen. Do not use compressed air from an ordinary air compressor, as oil particles in the air could contaminate the circuit board.
5. After cleaning or parts replacement check to see that any components connected to the Teflon insulators are not physically touching the board or adjacent parts.

SECTION 9
REPLACEABLE PARTS

9.1 INTRODUCTION

This section contains replacement parts information, component location drawings and schematic diagrams for the Model 595.

9.2 PARTS LIST

Parts are listed alphanumerically in order of their circuit designations. Table 9-1 contains parts list information for the mother board. Table 9-2 contains parts list information for the display board. Table 9-3 contains parts list information for the preamp board. Table 9-4 contains a miscellaneous parts list for the Model 595.

9.3 ORDERING INFORMATION

To place an order, or to obtain information concerning replacement parts, contact your Keithley representative or the factory. See inside front cover for addresses. When ordering include the following information:

1. Instrument Model Number
2. Instrument Serial Number
3. Parts Description
4. Circuit Designation (if applicable)
5. Keithley Part Number

If an additional instruction manual is required, order the manual package (Keithley Part Number 595-901-00). The manual package contains an instruction manual and any applicable addenda.

9.4 FACTORY SERVICE

If the instrument is to be returned to the factory for service, please complete the service form which follows this section and return it with the instrument.

9.5 SCHEMATIC DIAGRAMS AND COMPONENT LOCATION DRAWINGS

Schematic diagrams and component location drawings follow the appropriate replaceable parts list for that particular board.

Table 9-1. Mother Board, Parts List

Circuit Desig.	Description	Schematic Location	Keithley Part No.
C101	Capacitor, 4700μF, 16V, Aluminum Electrolytic	1/B6	C-313-4700
C102	Capacitor, 0.1μF, 50V, Ceramic Film	2/G5	C-365-.1
C103	Capacitor, 2200μF, 25V, Aluminum Electrolytic	1/B5	C-314-2200
C104	Capacitor, 10μF, 25V, Aluminum Electrolytic	1/C6	C-314-10
C105	Capacitor, 1μF, 50V, Ceramic Film	2/C1	C-237-1
C106	Capacitor, 10μF, 20V, Tantalum	2/C2	C-179-10
C107	Capacitor, 22pF, 1000V, Ceramic Disc	2/B5	C-64-22p
C108	Capacitor, 2200μF, 25V, Aluminum Electrolytic	1/B5	C-314-2200
C109	Capacitor, 0.1μF, 50V, Ceramic Film	2/D2	C-365-.1
C110	Capacitor, 470μF, 50V, Aluminum Electrolytic	1/B5	C-276-470
C111	Capacitor, 470μF, 50V, Aluminum Electrolytic	1/B5	C-276-470
C112	Capacitor, 22pF, 1000V, Ceramic Disc	2/B6	C-64-22p
C113	Capacitor, 0.1μF, 50V, Ceramic Film	2/G3	C-365-.1
C114	Capacitor, 1μF, 50V, Ceramic Film	2/D1	C-237-1
C115	Capacitor, 1μF, 50V, Ceramic Film	1/C5	C-237-1
C116	Capacitor, 1μF, 50V, Ceramic Film	1/C5	C-237-1
C117	Capacitor, 0.1μF, 50V, Ceramic Film	2/F2	C-365-.1
C118	Capacitor, 0.1μF, 50V, Ceramic Film	2/H1	C-365-.1
C119	Capacitor, 0.01μF, 500V, Ceramic Disc	1/D1	C-22-.01
C120	Capacitor, 0.01μF, 500V, Ceramic Disc	3/F2	C-22-.01
C121	Capacitor, 0.1μF, 50V, Ceramic Film	3/F3	C-365-.1
C122	Capacitor, 0.1μF, 50V, Ceramic Film	3/F1	C-365-.1
C123	Capacitor, 0.1μF, 50V, Ceramic Film	3/B4	C-365-.1
C124	Capacitor, 0.1μF, 50V, Ceramic Film	3/F4	C-365-.1
C125	Capacitor, 10μF, 25V, Aluminum Electrolytic	1/E2	C-314-10
C126	Capacitor, 10μF, 25V, Aluminum Electrolytic	1/D2	C-314-10
C127	Capacitor, .0047μF, 100V, Ceramic Disc	1/G3	C-22-.0047
C128	Capacitor, 33pF, 500V, Ceramic Disc	3/G3	C-22-33p
C129	Capacitor, 150pF, 500V, Ceramic Disc	3/G3	C-64-150p
C130	Capacitor, 10μF, 25V, Aluminum Electrolytic	3/B4	C-314-10
C131	Capacitor, 100pF, 1000V, Ceramic Disc	3/C3	C-64-100p
C132	Capacitor, 15pF, 1000V, Ceramic Disc	3/D4	C-64-15p
C133	Capacitor, 82pF, 1000V, Ceramic Disc	3/D4	C-64-82p
C134	Capacitor, 1000pF, 1000V, Ceramic Disc	3/E5	C-64-1000p
C135	Capacitor, 0.1μF, 50V, Ceramic Film	3/E5	C-237-.1
C136	Capacitor, .015μF, 500V, Ceramic Disc	1/D3	C-22-.015
C137	Capacitor, .0047μF, 100V, Metal Polypropylene	3/D3	C-306-.0047
C138	Capacitor, 0.47μF, 50V, Ceramic Film	1/E4	C-237-.47
C139	Capacitor, 33pF, 1000V, Ceramic Disc	1/F3	C-64-33p
C140	Capacitor, 2200pF, 1000V, Ceramic Disc	1/F2	C-22-2200p
C141	Capacitor, 0.1μF, 16V, Ceramic Disc	1/F3	C-22-.02
C142	Capacitor, 4.7μF, 25V, Aluminum Electrolytic	1/F4	C-314-4.7
C143	Capacitor, 0.01μF, 500V, Ceramic Disc	1/H3	C-22-.01
C144	Capacitor, 10μF, 20V, Tantalum	3/G1	C-179-10
C145	Capacitor, 0.1μF, 50V, Ceramic Film	—	C-237-.1
CR101	Diode, Silicon, 1N4006	1/B5	RF-38
CR102	Diode, Silicon, 1N4148	2/A3	RF-28
CR103	Diode, Silicon, 1N4148	2/A3	RF-28
CR104	Diode, Silicon, 1N4148	2/B2	RF-28
CR105	Diode, Silicon, 1N4148	2/B2	RF-28

Table 9-1. Mother Board, Parts List (Cont.)

Circuit Desig.	Description	Schematic Location	Keithley Part No.
CR106	Diode, Silicon, 1N4006	2/B1	RF-28
CR107	Diode, Silicon, 1N4006	1/B5	RF-38
CR108	Diode, Silicon, 1N4006	1/B5	RF-38
CR109	Diode, Silicon, 1N4006	1/B6	RF-38
CR110	Bridge, Silicon, 1A, 100PIV	1/B5	RF-52
CR111	Diode, Silicon, 1N4148	1/F3	RF-28
CR112	Diode, Silicon, 1N4148	1/F3	RF-28
CR113	Not Used		
CR114	Diode, Silicon, 1N4148	1/F2	RF-28
CR115	Diode, Silicon, 1N4148	1/F4	RF-28
CR116	Diode, Silicon, 1N4148	3/E4	RF-28
CR117	Diode, Silicon, 1N4006	1/E4	RF-38
F101	Line Fuse, 1/8A, 250V, 3AG, SLO-BLO (105-125V operation)	1/A4	FU-20
F101	Line Fuse, 1/16A, 250V, 3AG, SLO-BLO (210-250V operation)	1/A4	FU-21
J1012	Connector	2/H2	CS-507
J1013	Connector	1/A4	CS-388
J1015	Connector	1/H3	CS-545
J1018	Connector, 3 pin	2/A2	CS-339-3
J1019	Connector	2/H4	CS-389-4
J1020	Connector, 14 pin	3/A4	CS-389-5
J1021	Socket	2/D1	SO-68
K101	Relay	Sev	RL-90
Q101	Transistor, Silicon, NPN, TIP-49	1/E1	TG-137
Q102	Transistor, Silicon, NPN, 2N3904	1/D1	TG-47
Q103	Transistor, Silicon, NPN, 2N3904	1/F3	TG-47
Q104	Transistor, Silicon, PNP, 2N3906	1/F3	TG-84
Q105	Transistor, Dual, JFET	3/D4	TG-175
Q106	Transistor, Silicon, PNP, 2N3906	3/B5	TG-84
Q107	Transistor, Silicon, PNP, 2N3906	1/G2	TG-84
Q108	Transistor, N-Channel, JFET	1/D5	TG-128
Q109	Transistor, N-Channel, JFET	3/D3	TG-128
Q110	Transistor, N-Channel, JFET	3/D3	TG-174
Q111	Transistor, P-Channel, JFET	3/D3	TG-166
Q112	Not Used		
Q113	Transistor, NPN, Silicon, Annular	1/G2	TG-146
Q114	Transistor, PNP, Silicon, Annular	1/G4	TG-147
Q115	Transistor, N-Channel Enhancement Mode MOSFET	1/F4	TG-177
Q116	Transistor, Silicon, NPN, 2N3904	3/D1	TG-47
R101	Resistor, 100Ω, 5%, ¼W, Composition	2/A3	R-76-100
R102	Resistor, 100Ω, 5%, ¼W, Composition	2/B2	R-76-100
R103	Resistor, 430Ω, 5%, ¼W, Composition	2/A4	R-76-430
R104	Resistor, 30kΩ, 5%, ¼W, Composition	2/C1	R-76-30k
R105	Resistor, Thick Film	Sev	TF-183-1
R106	Resistor, 10MΩ, 10%, ¼W, Composition	1/C6	R-76-10M
R107	Resistor, Thick Film	Sev	TF-179-1
R108	Resistor, Thick Film	Sev	TF-179-1

Table 9-1. Mother Board, Parts List (Cont.)

Circuit Desig.	Description	Schematic Location	Keithley Part No.
R109	Resistor, 10MΩ, 10%, ¼W, Composition	2/C5	R-76-10M
R110	Resistor, 30kΩ, 5%, ¼W, Composition	1/C5	R-76-30k
R111	Resistor, 30kΩ, 5%, ¼W, Composition	1/C5	R-76-30k
R112	Resistor, 100kΩ, 5%, ¼W, Composition	2/B5	R-76-100k
R113	Resistor, 1kΩ, 5%, ¼W, Composition	1/D1	R-76-1k
R114	Resistor, 6.19kΩ, 0.1%, $^1/_8$W	1/D1	R-176-6.19k
R115	Resistor, 6.8kΩ, ¼W, Composition	1/F2	R-76-6.8k
R116	Resistor, 100kΩ, 5%, ¼W, Composition	1/G3	R-76-100k
R117	Resistor, 1kΩ, 5%, ¼W, Composition	3/G1	R-76-1k
R118	Resistor, 5.49kΩ, 1%, $^1/_8$W, Composition	1/D5	R-88-5.49k
R119	Resistor, 22.5kΩ, 0.1%, $^1/_{10}$W, Metal Film	1/D1	R-263-22.5k
R120	Resistor, 9.76kΩ, 1%, $^1/_8$W, Composition	1/D5	R-88-9.76k
R121	Resistor, 100Ω, 5%, ¼W, Composition	1/F3	R-76-100
R122	Resistor, 470Ω, ¼W, Composition	1/G3	R-76-470
R123	Resistor, 180Ω, 5%, ¼W, Composition	1/G3	R-76-180
R124	Resistor, 229Ω, 0.1%, $^1/_{10}$W, Metal Film	1/D1	R-263-229
R125	Resistor, 180Ω, 5%, ¼W, Composition	1/G3	R-76-180
R126	Resistor, 470Ω, 5%, ¼W, Composition	1/G3	R-76-470
R127	Resistor, 1.87kΩ, 1%, $^1/_8$W, Composition	1/D4	R-88-1.87k
R128	Resistor, 138Ω, 0.1%, $^1/_{10}$W, Metal Film	1/D2	R-263-138
R129	Resistor, 100Ω, 1%, $^1/_8$W, Composition	1/D4	R-88-100
R130	Not Used		
R131	Resistor, 45.9Ω, 0.1%, $^1/_{10}$W, Metal Film	1/D2	R-263-45.9
R132	Resistor, 402kΩ, 1%, $^1/_8$W, Composition	1/D4	R-88-402k
R133	Resistor, 6.8kΩ, 5%, ¼W, Composition	1/F4	R-76-6.8k
R134	Resistor, 45.9Ω, 0.1%, $^1/_{10}$W, Metal Film	1/D2	R-263-45.9
R135	Resistor, 1kΩ, 5%, ¼W, Composition	1/G4	R-76-1k
R136	Resistor, 15MΩ, 10%, ¼W, Composition	3/G2	R-76-15M
R137	Resistor, 2.2kΩ, 5%, ¼W, Composition	3/G2	R-76-2.2k
R138	Resistor, 200kΩ, 0.1%, $^1/_{10}$W, Metal Film	1/E2	R-263-200k
R139	Resistor, 200kΩ, 5%, ¼W, Composition	1/F4	R-76-200k
R140	Resistor Set, 10k, includes R140 and R143	1/E3	R-332
R141	Resistor, 100kΩ, 5%, ¼W, Composition	1/G4	R-76-100k
R142	Resistor, 22kΩ, 5%, ¼W, Composition	3/E4	R-76-22k
R143	Resistor Set, 10k, includes R140 and R143	1/E4	R-332
R144	Resistor, 100kΩ, 5%, ¼W, Composition	1/G2	R-76-100k
R145	Resistor, 1.1kΩ, 1%, $^1/_8$W, Composition	3/A4	R-88-1.1k
R146	Resistor, 22kΩ, 5%, ¼W, Composition	3/E4	R-76-22k
R147	Resistor, 4.02kΩ, 1%, $^1/_8$W, Composition	3/B5	R-88-4.02k
R148	Resistor, 10kΩ, 5%, ¼W, Composition	1/D4	R-76-10k
R149	Resistor, 7.78kΩ, 0.1%, $^1/_8$W	3/C4	R-176-7.78k
R150	Resistor, 430Ω, 5%, ¼W, Composition	3/G3	R-76-430
R151	Resistor, 10kΩ, 1%, $^1/_8$W, Composition	3/B5	R-88-10k
R152	Resistor, 100kΩ, 0.1%, $^1/_{10}$W, Metal Film	1/E3	R-263-100k
R153	Resistor, 1MΩ, 0.1%, $^1/_8$W	3/D4	R-176-1M
R154	Resistor, 10kΩ, 5%, ¼W, Composition	1/G2	R-76-10k
R155	Resistor, 10kΩ, 5%, ¼W, Composition	3/D3	R-76-10k
R156	Resistor, Thick Film	3/A5	TF-150
R157	Resistor, 10kΩ, 5%, ¼W, Composition	1/G2	R-76-10k
R158	Resistor, 17.4kΩ, 1%, $^1/_8$W, Composition	3/C3	R-88-17.4k
R159	Resistor, 3.3kΩ, 5%, ¼W, Composition	1/E3	R-76-3.3k

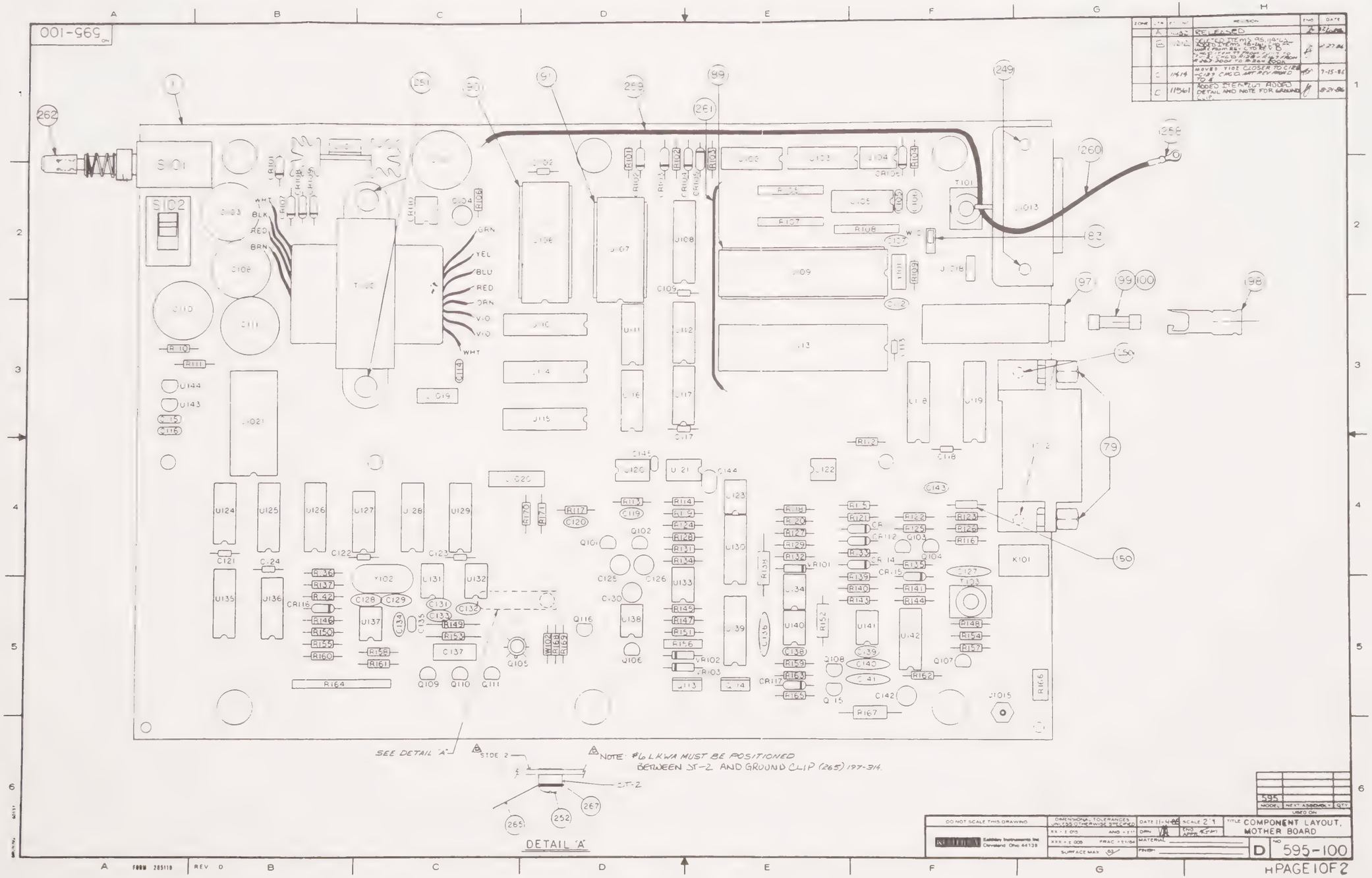
Table 9-1. Mother Board, Parts List (Cont.)

Circuit Desig.	Description	Schematic Location	Keithley Part No.
R160	Resistor, 10kΩ, 5%, ¼W, Composition	3/C2	R-76-10k
R161	Resistor, 28.7kΩ, 1%, $^1/_8$W, Composition	3/C4	R-88-28.7k
R162	Resistor, 1kΩ, 5%, ¼W, Composition	1/F4	R-76-1k
R163	Resistor, 10kΩ, 5%, ¼W, Composition	1/E4	R-76-10k
R164	Resistor, Thick Film	Sev	TF-196
R165	Resistor, 47kΩ, 5%, ¼W, Composition	1/E4	R-76-47k
R166	Potentiometer, 1kΩ	1/D5	RP-111-1k
R167	Resistor, 200kΩ, .1%, $^1/_{10}$W, Metal Film	1/F3	R-263-200k
R168	Resistor, 10kΩ, 5%, ¼W, Composition	3/C1	R-76-10k
R169	Resistor, 10kΩ, 5%, ¼W, Composition	3/D1	R-76-10k
R170	Resistor, 10kΩ, 5%, ¼W, Composition	3/B3	R-76-10k
R171	Resistor, 10kΩ, 5%, ¼W, Composition	3/B3	R-76-10k
S101	Switch, Line	1/A5	SW-466
S102	Switch, Voltage Select	1/A5	SW-397
T101	Transformer	1/A4	TR-214
T102	Transformer	1/B5	TR-236
T102	Transformer (for Japanese version)	1/B5	TR-237
T103	Transformer	1/G3	TR-214
U101	IC 3-Terminal +5V Regulator and heat sink	1/C6	32469-2
U102	IC, Quad 2-Input NAND Gate, 74LS00	Sev	IC-163
U103	IC, 74HC4040	2/F4	IC-407
U104	IC, 16 × 16 Bit Serial NVRAM, X2443P	2/B2	IC-353
U105	IC, Dual "D" Type Flip-Flop, 4013	Sev	IC-103
U106	IC, PROM, 27128	2/G4	595-800**
U107	IC, 2k × 8 Static CMOS RAM, 6116	2/E4	LSI-58
U108	IC, Octal Tri-State Latch, 74HC373	2/D2	IC-338
U109	IC, 8-Bit CMOS Microprocessor, 146805E2	2/C1	LSI-60
U110	IC, Tri-State Octal Latch, 74HC373	2/E1	IC-338
U111	IC, Quad 2-Input NAND Gate, 74HC00	2/D5	IC-351
U112	IC, Triple 3-Input OR Gate, CD4075BE	Sev	IC-143
U113	IC, GPIB Adapter, 9914A	2/G2	LSI-49
U114	IC, Tri-State Octal Latch, 74HC373	2/F2	IC-338
U115	IC, Tri-State Octal Latch, 74HC373	2/H5	IC-338
U116	IC, Quad 2-Input NOR Gate, 74HC02	Sev	IC-412
U117	IC, Triple 3-Input NAND Gate, 74HC10	2/D5	IC-341
U118	IC, Octal GPIB Transceiver, SN75161A	2/H2	IC-299
U119	IC, Octal GPIB Transceiver, SN75160A	2/H1	IC-298
U120	IC, Opto Coupler, HCPL-2601	2/A4	IC-239
U121	IC, Opto Coupler, HCPL-2601	3/G1	IC-239
U122	IC, Opto Isolator, FCD-820	2/B5	IC-82
U123	IC, Low Noise Op Amp, LT1012	1/D3	IC-394
U124	IC, Dual D Flip-Flop, 74HC74	3/F3	IC-337
U125	IC, 74HC4040	3/E3	IC-407
U126	IC, CMOS Static Shift Register, CD4015AE	Sev	IC-136
U127	IC, Quad 2-Input NOR Gate, 74HC02	Sev	IC-412
U128	IC, 8 Stage Shift-Store Register, MC14094	3/C2	IC-251
U129	IC, Triple 2-Channel Multiplexer, CD4053BC	3/B3	IC-283
U130	IC, Analog Multiplexer, 4051	1/B3	IC-277

**Order same software as presently installed. For example, if the software revision level is B8, then order 595-800-B8.

Table 9-1. Mother Board, Parts List (Cont.)

Circuit Desig.	Description	Schematic Location	Keithley Part No.
U131	IC, Linear Op Amp, 308A	3/C3	IC-203
U132	IC, Inverting High-Speed Op Amp, MP5501CP	3/D4	IC-414
U133	IC, General Purpose Op Amp, MP5502DP	1/D1	IC-413
U134	IC, Operational Amplifier, 741	1/D5	IC-42
U135	IC, Triple 2-Channel Multiplexer, CD4053BC	3/D3	IC-283
U136	IC, Triple 3-Input NAND Gate, 74HC10	Sev	IC-341
U137	IC, Dual Voltage Comparator, LM393	Sev	IC-343
U138	IC, Programmable Operational Amplifier, TLC271	3/A5	IC-347
U139	CMOS Serial Input 12-Bit DAC, 7543KN	1/C3	IC-419
U140	IC, Operational Amplifier, OP-14E	Sev	IC-423
U141	IC, Linear Op Amp, 308A	1/F3	IC-203
U142	IC, Quad Comparator, LM339	Sev	IC-219
U143	IC, Regulator, 78L15	1/C5	IC-170
U144	IC, 15V, Voltage Regulator, LM320LZ-15	1/C5	IC-253
VR101	Regulator, Zener Diode, 6.35V, 400mW	1/D5	DZ-58
VR102	Regulator, Zener Diode, 6.35V, 400mW	3/A5	DZ-58
VR103	Zener Diode, DIOD-VRF109.1	3/B4	DZ-14
W101	Jumper	2/C3	CS-476
W102	Not used		
W103	Jumper	—	SC-68
Y101	Crystal, 3.276800MHz, ±0.25%	2/C5	CR-21
Y102	Crystal, 1.2288MHz	3/G3	CR-19


595-100
S101
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J102
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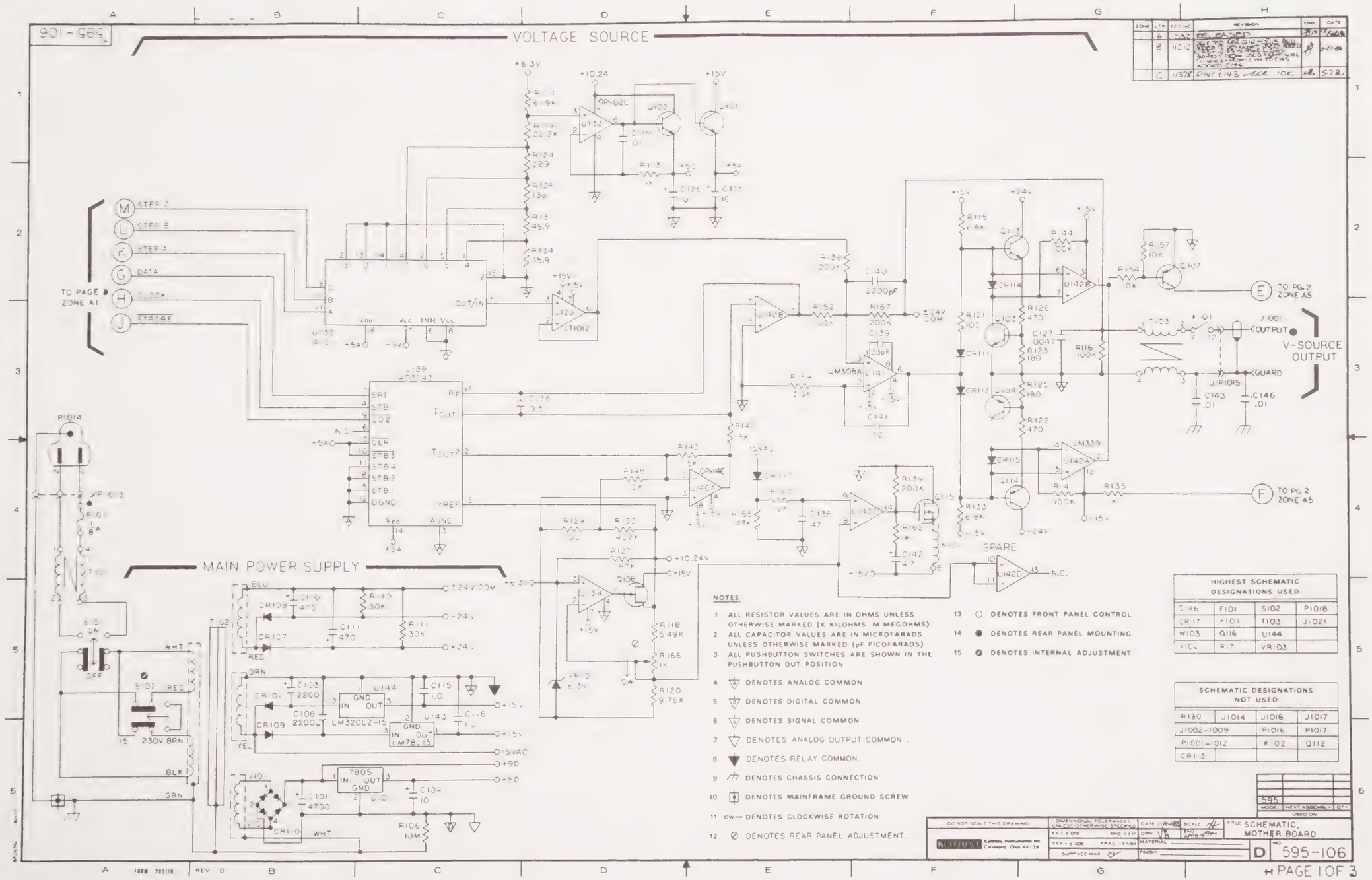

VOLTAGE SOURCE
MAIN POWER SUPPLY
SPARE
TO PAGE 3 ZONE A1
TO PG 2 ZONE A5
TO PG 2 ZONE A5
V-SOURCE OUTPUT
OUTPUT
GUARD
NOTES
1 ALL RESISTOR VALUES ARE IN OHMS UNLESS OTHERWISE MARKED (K KILOHMS M MEGOHMS)
2 ALL CAPACITOR VALUES ARE IN MICROFARADS UNLESS OTHERWISE MARKED (pF PICOFARADS)
3 ALL PUSHBUTTON SWITCHES ARE SHOWN IN THE PUSHBUTTON OUT POSITION
4 DENOTES ANALOG COMMON
5 DENOTES DIGITAL COMMON
6 DENOTES SIGNAL COMMON
7 DENOTES ANALOG OUTPUT COMMON .
8 DENOTES RELAY COMMON.
9 DENOTES CHASSIS CONNECTION
10 DENOTES MAINFRAME GROUND SCREW
11 CW DENOTES CLOCKWISE ROTATION
12 DENOTES REAR PANEL ADJUSTMENT.
13 DENOTES FRONT PANEL CONTROL
14 DENOTES REAR PANEL MOUNTING
15 DENOTES INTERNAL ADJUSTMENT
HIGHEST SCHEMATIC DESIGNATIONS USED
SCHEMATIC DESIGNATIONS NOT USED
SCHEMATIC, MOTHER BOARD
595-106
PAGE 1 OF 3

Figure 9-2. Mother Board, Schematic Diagram, Dwg. No. 595-106 (sheet 1 of 3)

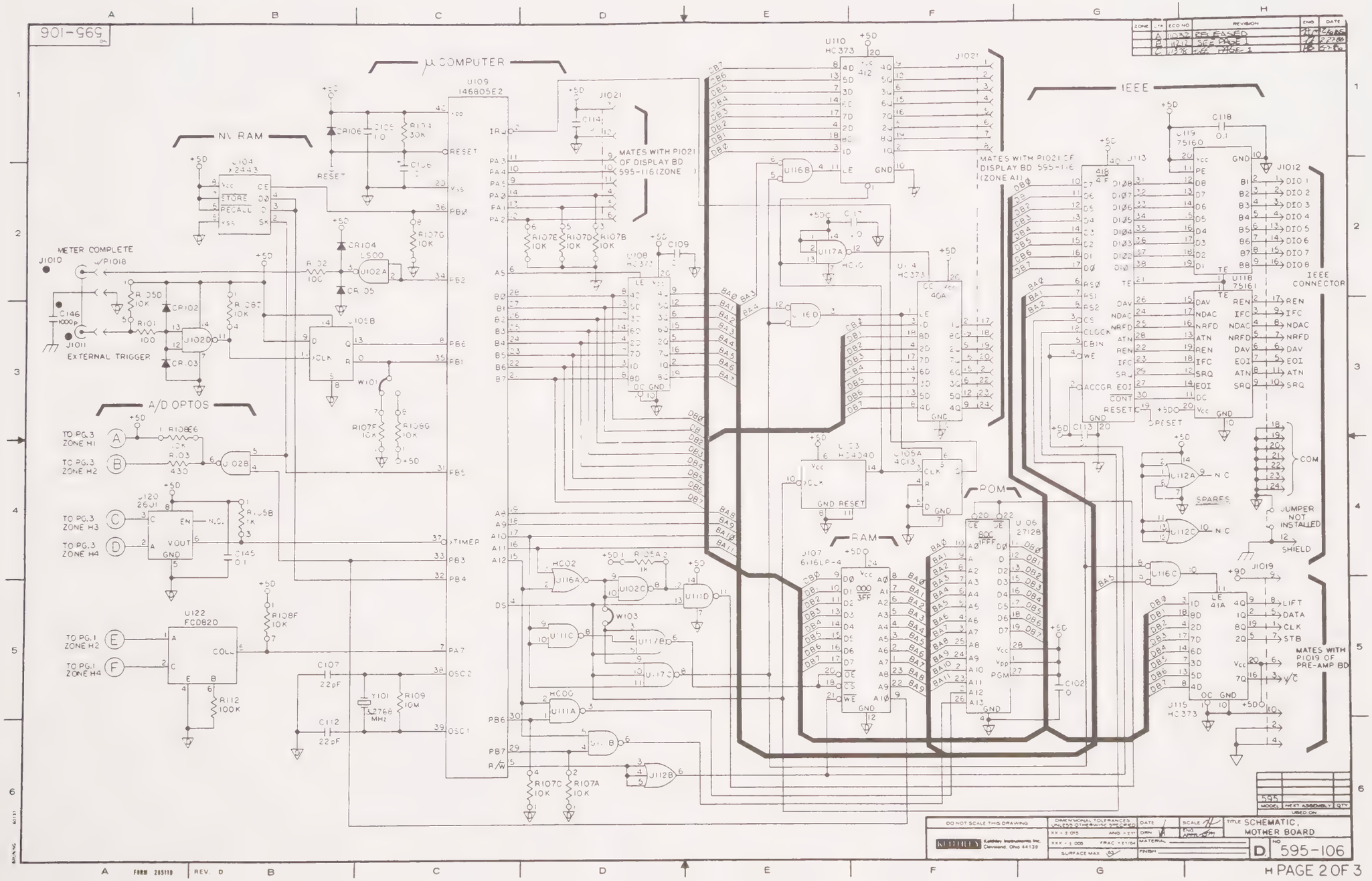


Figure 9-2. Mother Board, Schematic Diagram, Dwg. No. 595-106 (sheet 2 of 3)

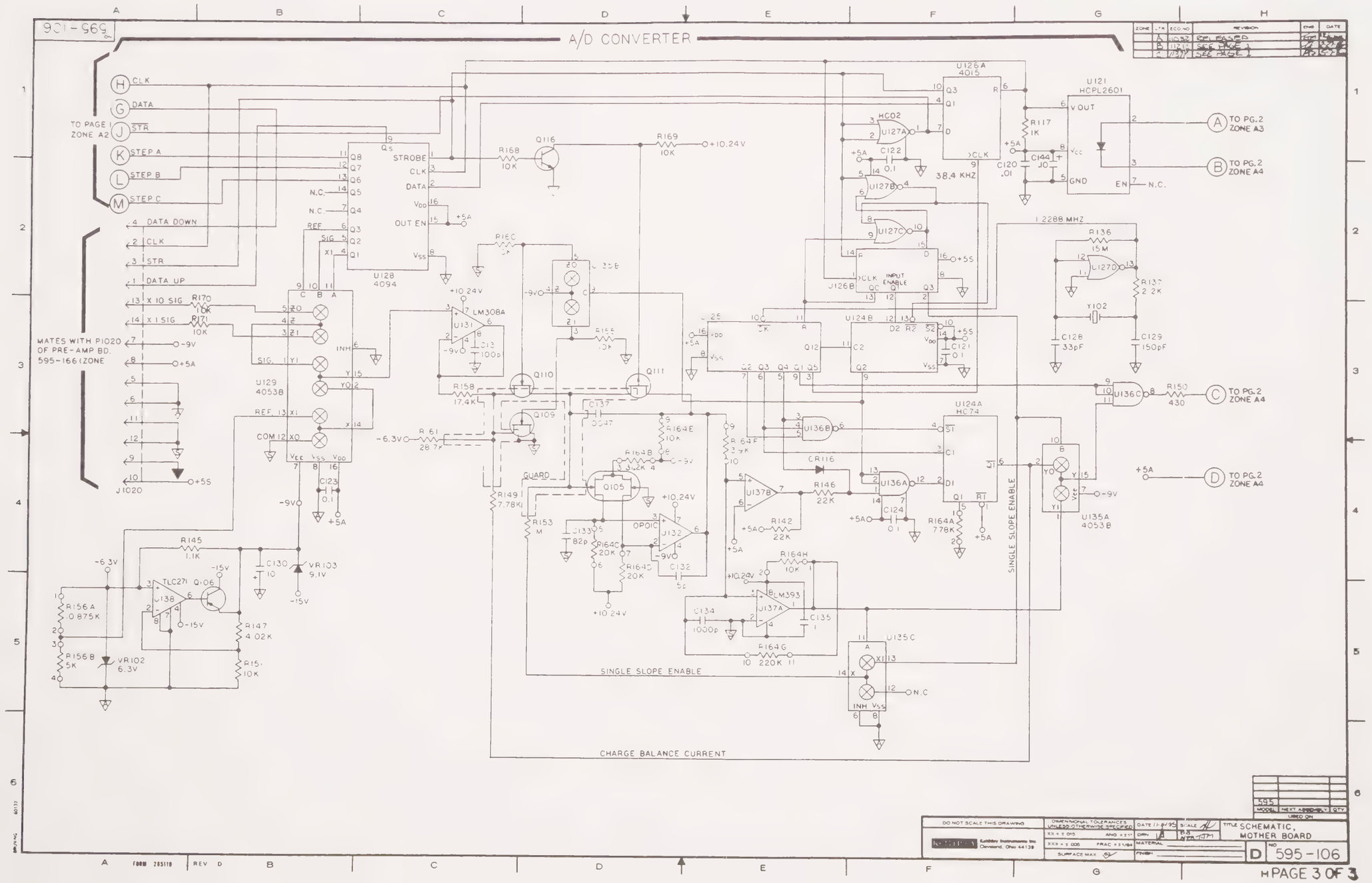


Figure 9-2. Mother Board, Schematic Diagram, Dwg. No. 595-106 (sheet 3 of 3)

Table 9-2. Display Board, Parts List

Circuit Desig.	Description	Schematic Location	Keithley Part No.
C201	Capacitor, 10μF, 20V, Tantalum	A3	C-179-10
DS201	Display, Digital, "–1"	C1	617-603
DS202	Display, 7-Segment, "8"	C1	617-604
DS203	Display, 7-Segment, "8"	D1	617-604
DS204	Display, 7-Segment, "8"	E1	617-604
DS205	Display, 7-Segment, "8"	E1	617-604
DS206	Display, Dual 14-Segment	G1	DD-39
DS207	LED, Red	H1	PL-71
DS208	LED, Red	H1	PL-71
DS209	LED, Red	H2	PL-71
DS210	LED, Red	H2	PL-71
DS211	LED, Red	H2	PL-71
DS212	LED, Red	H2	PL-71
DS213	LED, Red	H2	PL-71
DS214	LED, Red	H2	PL-71
DS215	LED, Red	H3	PL-71
DS216	LED, Red	H3	PL-71
DS217	LED, Red	H3	PL-71
DS218	LED, Red	H3	PL-71
DS219	LED, Red	H4	PL-71
DS220	LED, Yellow	H4	PL-72
DS221	LED, Red	H4	PL-71
DS222	LED, Red	H4	PL-71
DS223	LED, Red	H5	PL-71
P1021	Cable, Ribbon	A1	CA-30-1
R201	Resistor, Thick Film	B1	TF-141
R202	Resistor, Thick Film	B3	TF-141
S201	Switch, Pushbutton	D4	SW-435
S202	Switch, Pushbutton	D4	SW-435
S203	Switch, Pushbutton	D4	SW-435
S204	Switch, Pushbutton	D4	SW-435
S205	Switch, Pushbutton	D4	SW-435
S206	Switch, Pushbutton	D4	SW-435
S207	Switch, Pushbutton	D4	SW-435
S208	Switch, Pushbutton	D4	SW-435
S209	Switch, Pushbutton	D4	SW-435
S210	Switch, Pushbutton	D5	SW-435
S211	Switch, Pushbutton	D5	SW-435
S212	Switch, Pushbutton	D5	SW-435
S213	Switch, Pushbutton	D5	SW-435
S214	Switch, Pushbutton	D5	SW-435
S215	Switch, Pushbutton	D5	SW-435
S216	Switch, Pushbutton	D5	SW-435
S217	Switch, Pushbutton	D5	SW-435
S218	Switch, Pushbutton	D5	SW-435
S219	Switch, Pushbutton	D5	SW-435

Table 9-2. Display Board, Parts List (Cont.)

Circuit Desig.	Description	Schematic Location	Keithley Part No.
U201	IC, UDN2585A	A1	IC-405
U202	IC, UDN2585A	A3	IC-405
U203	IC, 3 to 8 Line Decoder, 74HCT138	B3	IC-398
U204	IC, UDN2595A	D4	IC-406
U205	IC, UDN2595A	E4	IC-406
U206	IC, Analog Multiplexer, 4051	B5	IC-277

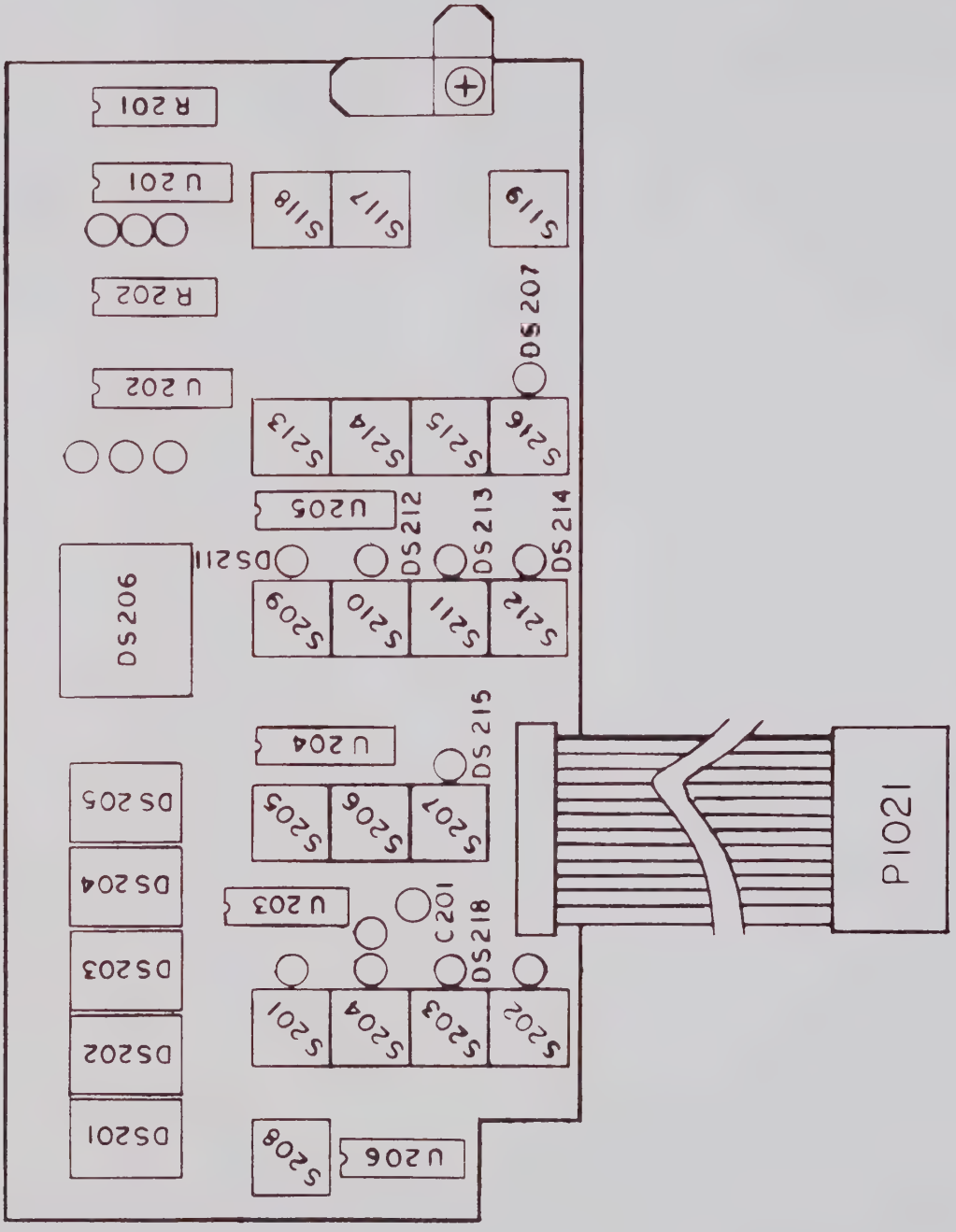
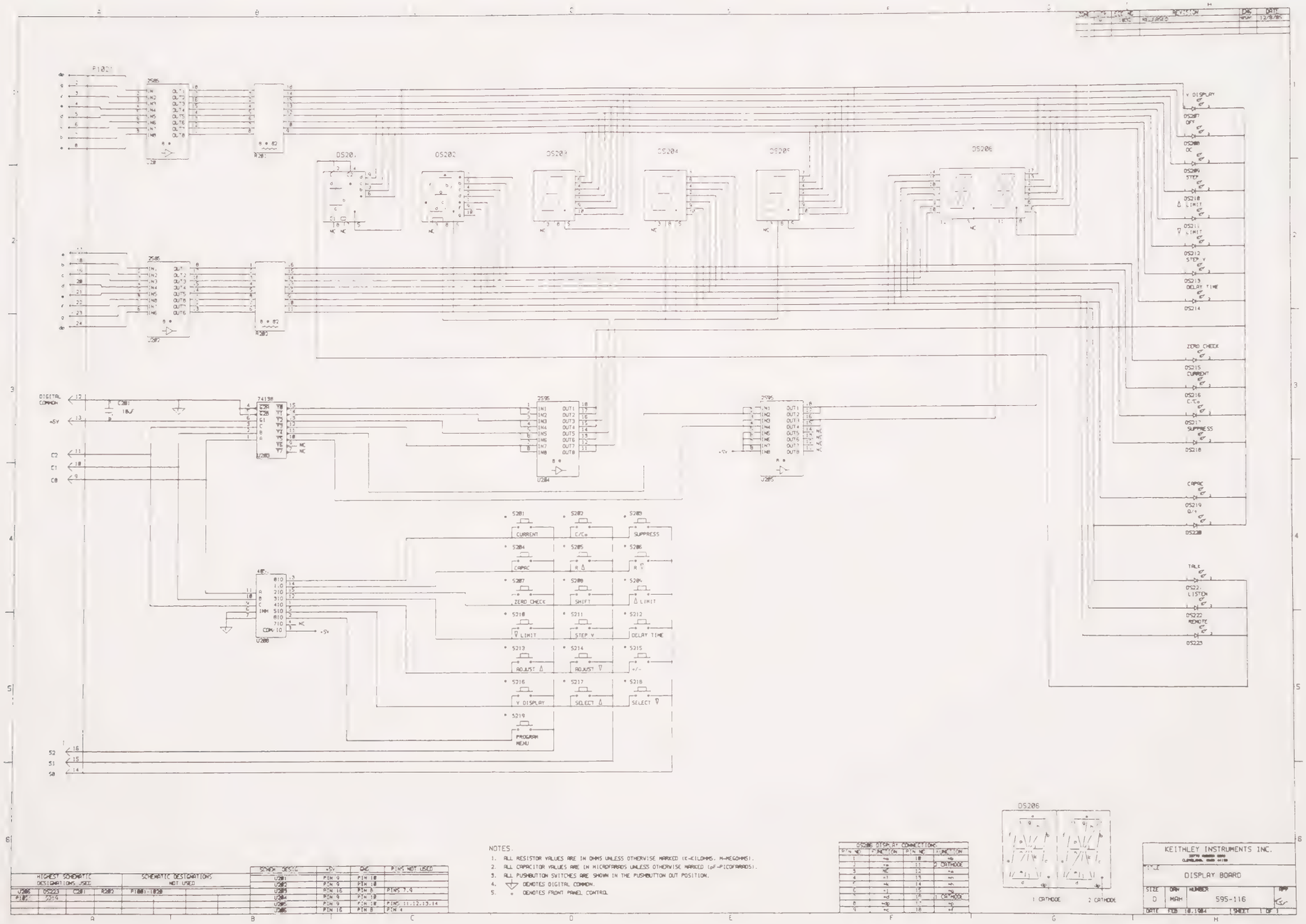


Figure 9-3. Display Board, Component Location Drawing, Dwg. No. 595-110



NOTES.

1. ALL RESISTOR VALUES ARE IN OHMS UNLESS OTHERWISE MARKED (K=KILOHMS, M=MEGOHMS).
2. ALL CAPACITOR VALUES ARE IN MICROFARADS UNLESS OTHERWISE MARKED (pF=PICOFARADS).
3. ALL PUSHBUTTON SWITCHES ARE SHOWN IN THE PUSHBUTTON OUT POSITION.
4. ⏚ DENOTES DIGITAL COMMON.
5. * DENOTES FRONT PANEL CONTROL

HIGHEST SCHEMATIC DESIGNATIONS USED				SCHEMATIC DESIGNATIONS NOT USED				SOCKET	SOCKET	+5V	GND	PINS NOT USED
U286	DS223	C281	R283	P1181-1858				U281		PIN 9	PIN 18	
P1187	7374							U282		PIN 9	PIN 18	
								U283		PIN 16	PIN 8	PINS 3,4
								U284		PIN 8	PIN 16	
								U285		PIN 9	PIN 18	PINS 11,12,13,14
								U286		PIN 16	PIN 8	PIN 4

DS206 SEGMENT CONNECTIONS

SEG	ANODE	PIN	SEG	ANODE	PIN
a	+a	1	f	+f	18
b	+b	13	g	+g	CATHODE
c	+c	12	d	+d	+a
e	+e	11	dp	+dp	+b
f	+f	10	b	+b	+c
g	+g	9	c	+c	+dp
a	+a	7	e	+e	+d
b	+b	6	CATHODE		

DS206

1 CATHODE 2 CATHODE

Figure 9-4. Display Board, Schematic Diagram, Dwg. No. 595-116

Table 9-3. Preamp Board, Parts List

Circuit Desig.	Description	Schematic Location	Keithley Part No.
C301	Capacitor, 10μF, 25V, Aluminum Electrolytic	E2	C-314-10
C302	Capacitor, selected	C4	595-600
C303	Capacitor, 91pF	C3	C-385-91p
C304	Capacitor, 1000pF, 630V, Polystyrene	C3	C-252-1000p
C305	Capacitor, 0.1μF, 100V, Metalized Polyester	D3	C-305-.1
C306	Capacitor, 0.1μF, 100V, Metalized Polyester	D3	C-305-.1
C307	Capacitor, 220pF, 1000V, Ceramic Disc	E4	C-64-220p
C308	Capacitor, 10pF, 1000V, Ceramic Disc	B4	C-64-10p
C309	Capacitor, 10μF, 25V, Aluminum Electrolytic	G3	C-314-10
C310	Capacitor, 10μF, 25V, Aluminum Electrolytic	G4	C-314-10
C311	Capacitor, 4.7μF, 25V, Aluminum Electrolytic	H3	C-314-4.7
C312	Capacitor, 0.1μF, 50V	G4	C-365-.1
C313	Capacitor, 0.1μF, 50V	H4	C-365-.1
C314	Capacitor, 0.1μF, 50V	G5	C-365-.1
C315	Capacitor, 0.1μF, 50V	H5	C-365-.1
C316	Capacitor, 100pF, 1000V, Ceramic Disc	G4	C-64-100p
C317	Capacitor, 100pF, 1000V, Ceramic Disc	F4	C-64-100p
C318	Capacitor, 100pF, 1000V, Ceramic Disc	G5	C-64-100p
C319	Capacitor, 100pF, 1000V, Ceramic Disc	F6	C-64-100p
C320	Capacitor, 22pF, 500V, Polystyrene	B3	C-138-22p
C321	Capacior, 680pF, 1000V, Ceramic Disc	D2	C-64-680p
C322	Capacitor, selected	C4	595-600
C323	Capacitor, 47pF, 500V, Polystyrene	C4	C-138-47p
CR301	Diode, Diffused, Silicon (DIOD-REC10075)	C2	RF-28
CR302	Diode, Diffused, Silicon (DIOD-REC10075)	G6	RF-28
CR303	Diode, Diffused, Silicon (DIOD-REC10075)	G6	RF-28
J1016	Connector	B6	CS-545
J1017	Connector	H4	CS-339-4
K301	Relay, Reed	Sev	RL-70
K302	Relay, Reed	Sev	RL-70
K303	Relay, Reed	Sev	RL-70
K304	Relay, Reed	Sev	RL-70
K305	Relay, Reed	Sev	RL-70
K306	Relay, Reed	Sev	RL-70
K307	Relay, Reed	Sev	RL-70
K308	Relay, Reed	Sev	RL-44
P1019	Cable Assembly	E3	CA-27-1
P1020	Cable Assembly	F1	CA-27-2
Q301	Transistor, PNP Silicon Annular, MPS-U60	C2	TG-177
Q302	Transistor, Selected, Dual JFET	D5	617-606
Q303	Transistor, N-Channel, JFET	B2	TG-174
Q304	Transistor, Dual NPN	A2	TG-91
Q305	Transistor, Dual NPN	A2	TG-91
Q306	Not Used		
Q307	Transistor, NPN Silicon, Annular, MPS-U60	G3	TG-145

Table 9-3. Preamp Board, Parts List (Cont.)

Circuit Desig.	Description	Schematic Location	Keithley Part No.
R301	Resistor, 243Ω, 1%, 1/8W, Composition	E2	R-88-243
R302	Resistor, 715Ω, 1%, 1/8W, Composition	E2	R-88-715
R303	Potentiometer, 5kΩ, 10%, .5W	D2	RP-104-5k
R304	Resistor, 10GΩ, 2%, 1.5W	C4	R-289-10G
R305	Resistor, 100MΩ, 1%, 1.5W,	C3	R-269-100M
R306	Resistor, 998kΩ, 0.1%, ¼W, Metal Film	C3	R-264-998k
R307	Resistor, 990kΩ, 0.1%, ¼W, Metal Film	D3	R-264-990k
R308	Resistor, 110kΩ, 0.1%, 1/10W, Metal Film	D4	R-263-110k
R309	Resistor, 10kΩ, 0.1%, 1/10W, Metal Film	C4	R-263-10k
R310	Resistor, 10MΩ, 10%, ¼W, Composition	B4	R-76-10M
R311	Resistor, 100kΩ, 5%, ¼W, Composition	C4	R-76-100k
R312	Resistor, 100kΩ, 5%, ¼W, Composition	C4	R-76-100k
R313	Resistor, 4.02kΩ, 1%, 1/8W, Composition	D4	R-88-4.02k
R314	Resistor, 402Ω, 1%, 1/8W, Composition	D4	R-88-402
R315	Potentiometer, 10kΩ, 25 Turn Trimpot	D5	RP-104-10k
R316	Resistor, 250GΩ, 5%, 1.5W,	B5	R-319-250G
R317	Potentiometer, 10kΩ, 25 Turn Trimpot	C5	RP-104-10k
R318	Resistor, 1.5kΩ, 1%, 1/8W, Composition	D5	R-88-16.5k
R319	Resistor, 24.9kΩ, 1%, 1/8W, Composition	D5	R-88-24.9k
R320	Resistor, 40.2Ω, 1%, 1/8W, Composition	D5	R-88-40.2
R321	Resistor, 2.2kΩ, 5%, ¼W, Composition	B5	R-76-2.2k
R322	Resistor, 5.1kΩ, 5%, ¼W, Composition	B5	R-76-5.1k
R323	Resistor, Set, 200kΩ	D6	R-322
R324	Resistor, Set, 200kΩ	D6	R-322
R325	Resistor, 33Ω, 10%, 2W, Composition	F3	R-3-33
R326	Resistor, 22Ω, 10%, 2W, Composition	G3	R-3-22
R327	Resistor, 35.7Ω, 1%, 1/8W, Composition	F3	R-88-35.7
R328	Resistor, 5.49kΩ, 1%, 1/8W, Composition	H3	R-88-5.49k
R329	Resistor, 402kΩ, 1%, 1/8W, Composition	H3	R-88-402k
R330	Resistor, 9.98kΩ, 0.1%, 1/10W, Metal Film	H3	R-263-9.98k
R331	Resistor, 4.59kΩ, 0.1%, 1/10W, Metal Film	H3	R-263-4.59k
R332	Resistor, 100Ω, 1%, 1/8W, Composition	H3	R-88-100
R333	Potentiometer, 2kΩ, 25 Turn Trimpot	F4	RP-104-2k
R334	Resistor, Set, 10kΩ	F4	R-332
R335	Resistor, Set, 10kΩ	G4	R-332
R336	Resistor, 2kΩ, 0.1%, 1/10W, Metal Film	H4	R-263-2k
R337	Resistor, 2kΩ, 0.1%, 1/10W, Metal Film	H4	R-263-2k
R338	Resistor, 10kΩ, 5%, ¼W, Composition	F5	R-76-10k
R339	Resistor, 10kΩ, 5%, ¼W, Composition	F5	R-76-10k
R340	Potentiometer, 2kΩ, 25 Turn Trimpot	F5	RP-104-2k
R341	Resistor, Set, 10kΩ	F5	R-332
R342	Resistor, Set, 10kΩ	G6	R-332
R343	Resistor, 2kΩ, 0.1%, 1/10W, Metal Film	H5	R-263-2k
R344	Resistor, 2kΩ, 0.1%, 1/10W, Metal Film	H5	R-263-2k
R345	Resistor, 100Ω, 5%, ¼W, Composition	H6	R-76-100
R346	Resistor, 47kΩ, 5%, ¼W, Composition	D2	R-76-47k
R347	Resistor, 47kΩ, 5%, ¼W, Composition	D2	R-76-47k
R348	Resistor, 10kΩ, 5%, ¼W, Composition	C2	R-76-10k
R349	Resistor, 100Ω,5%, ¼W, Composition	D2	R-76-100
R350	Resistor, Set, 200kΩ	B3	R-322
R351	Resistor, Set, 200kΩ	C2	R-322

Table 9-3. Preamp Board, Parts List (Cont.)

Circuit Desig.	Description	Schematic Location	Keithley Part No.
R352	Resistor, Set, 10kΩ	D2	R-332
R353	Resistor, Set, 10kΩ	D2	R-332
RT301	Thermistor	C5	RT-12
RT302	Thermistor	C5	RT-12
U301	IC, Hex Inverter, 74HC04	Sev	IC-354
U302	IC, 8-Stage Shift Register, MC14094BCP	D1	IC-251
U303	IC, Adjustable Regulator, LM337L	E1	IC-345
U304	IC, Operational Amplifier	D3	IC-316
U305	IC, Low Noise Op Amplifier	D6	IC-394
U306	CMOS Voltage Converter	G3	IC-287
U307	Programmable Operational Amplifier	H3	IC-347
U308	CMOS Serial Input 12-Bit DAC	F4	IC-419
U309	Linear Op Amplifier	G4	IC-203
U310	Linear Op Amplifier	F4	IC-203
U311	CMOS Serial Input 12-Bit DAC	F5	IC-419
U312	Linear Op Amplifier	G5	IC-203
U313	Linear Op Amplifier	F6	IC-203
U314	Inverting High Speed Operational Amplifier	D2	IC-414
VR301	Diode, Zener (DIOD-VRF108.2)	F3	DZ-61
VR302	Diode, Low Voltage Reference	H3	DZ-65
VR303	Diode, Zener (DIOD-VRF105.1)	G4	DZ-59
VR304	Diode, Zener (DIOD-VRF105.1)	G4	DZ-59
VR305	Diode, Zener (DIOD-VRF105.1)	G5	DZ-59
VR306	Diode, Zener (DIOD-VRF105.1)	G6	DZ-59
W301	Connector, Jumper	C5	CS-476

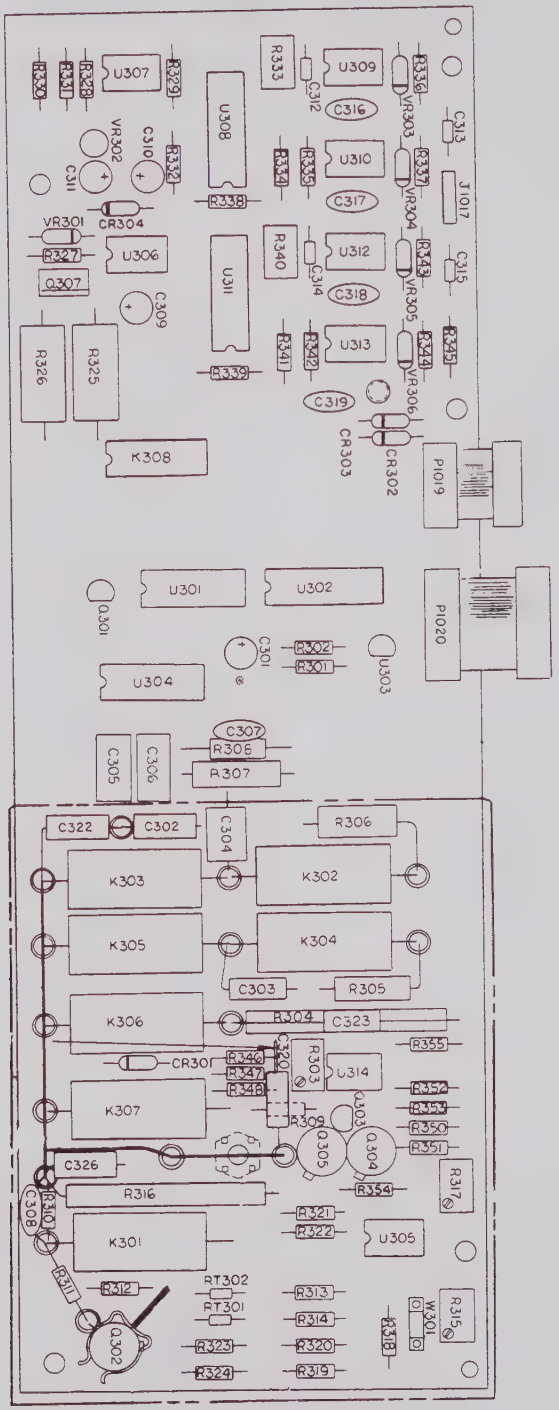


Figure 9-5. Preamp Board, Component Location, Dwg. No. 595-160

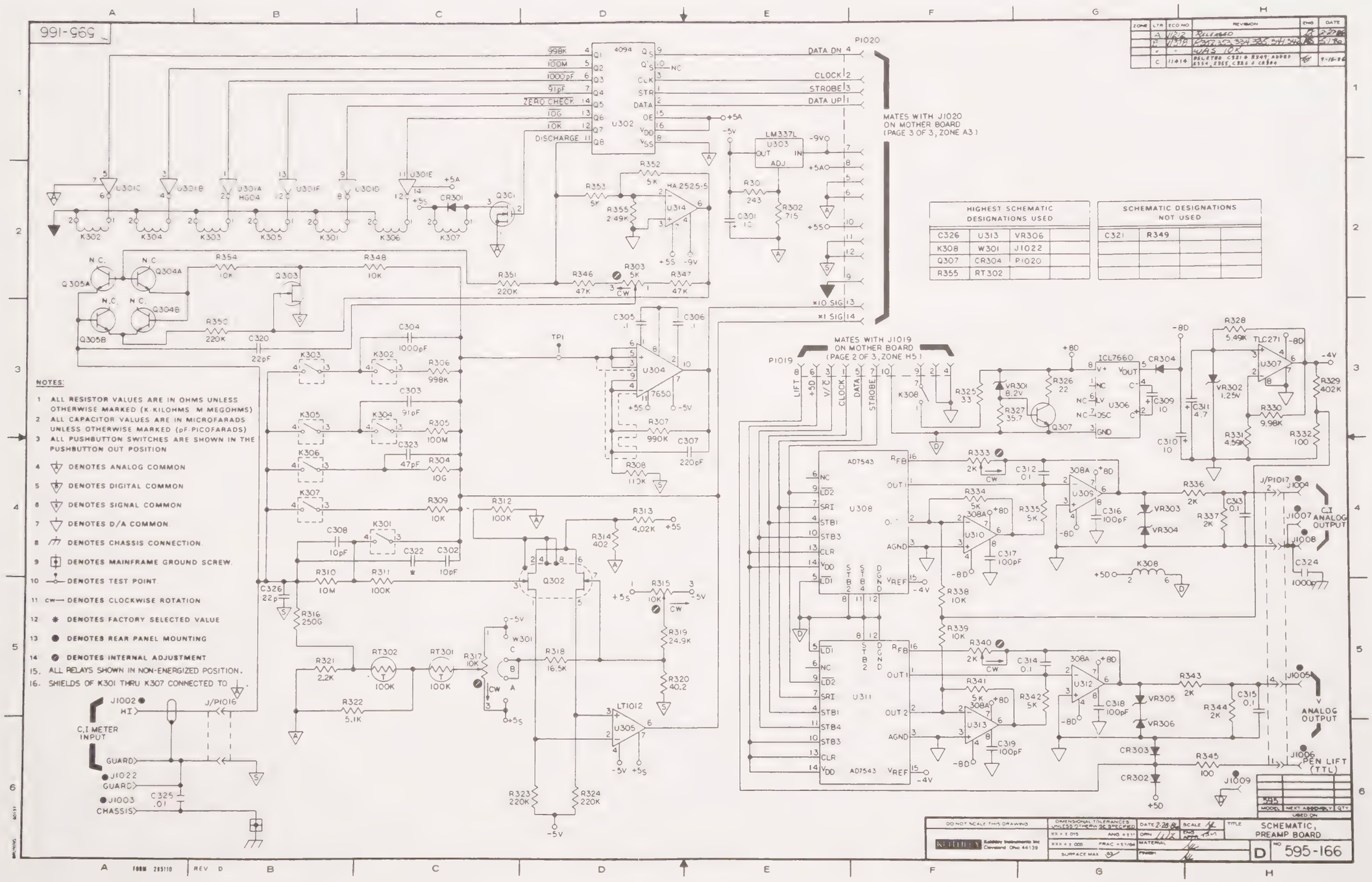

595-166
NOTES:
1 ALL RESISTOR VALUES ARE IN OHMS UNLESS OTHERWISE MARKED (K-KILOHMS M-MEGOHMS)
2 ALL CAPACITOR VALUES ARE IN MICROFARADS UNLESS OTHERWISE MARKED (pF-PICOFARADS)
3 ALL PUSHBUTTON SWITCHES ARE SHOWN IN THE PUSHBUTTON OUT POSITION
4 DENOTES ANALOG COMMON
5 DENOTES DIGITAL COMMON
6 DENOTES SIGNAL COMMON
7 DENOTES D/A COMMON
8 DENOTES CHASSIS CONNECTION
9 DENOTES MAINFRAME GROUND SCREW
10 DENOTES TEST POINT
11 CW DENOTES CLOCKWISE ROTATION
12 * DENOTES FACTORY SELECTED VALUE
13 DENOTES REAR PANEL MOUNTING
14 DENOTES INTERNAL ADJUSTMENT
15. ALL RELAYS SHOWN IN NON-ENERGIZED POSITION.
16. SHIELDS OF K301 THRU K307 CONNECTED TO
MATES WITH J1020 ON MOTHER BOARD (PAGE 3 OF 3, ZONE A3)
MATES WITH J1019 ON MOTHER BOARD (PAGE 2 OF 3, ZONE H5)
HIGHEST SCHEMATIC DESIGNATIONS USED
C326 U313 VR306
K308 W301 J1022
Q307 CR304 P1020
R355 RT302
SCHEMATIC DESIGNATIONS NOT USED
C321 R349
ZONE LTR ECO NO REVISION ENG DATE
C 11414 DELETED C321 & R349; ADDED R334, R335, C326 & CR304 9-15-86
DO NOT SCALE THIS DRAWING
Keithley Instruments Inc Cleveland Ohio 44139
SCHEMATIC, PREAMP BOARD
D 595-166

Figure 9-6. Preamp Board, Schematic Diagram, Dwg. No. 595-166

Table 9-4. Miscellaneous Parts, Parts List

Quantity	Description	Keithley Part Number
	Bottom Cover	
1	Bottom Cover	617-318
1	Bottom Cover Shield	617-321
1	Insulator (installed on bottom cover shield)	595-303
1	Shield (installed on insulator)	595-302
1	Grounding Clip (for above shield)	197-314
1	Tilt Bail	30544
1	Dress Panel for tilt bail	30587
1	Drive Pin for tilt bail	FA-143-1
4	Foot	FE-14
	Top Cover	
1	Top Cover	30540
1	Shield	617-322
	Front Panel	
1	Front Panel (includes Display Window)	617-301
1	Front Panel Overlay	595-310
1	Front Panel Shield	617-323
	Rear Panel	
1	Rear Panel	595-311
	METER INPUT Cable Assembly	
1	Right Angle SMB connector, female	CS-546
1	BNC connector, female	CS-548
1	Coaxial Cable	SC-110
	V SOURCE OUTPUT Cable Assembly	
1	Straight SMB connector, female	CS-550
1	BNC connector, female	CS-548
1	Coaxial Cable	SC-110
2	BNC connector, female, (METER COMPLETE OUTPUT and EXTERNAL TRIGGER INPUT)	CS-520
1	Binding Post, White	BP-11-9
1	Binding Post (chassis ground)	BP-15
3	Binding Post, Black	BP-11-0
3	Binding Post, Red	BP-11-2
1	Shorting Link	BP-6
1	Ground Clip	775-306
4	BNC Protection Cap	CAP-18
1	Line Cord	CO-7
1	BNC-to-BNC Cable Assembly	Model 4801
	Mother Board Mechanical Parts	
6	Collar	30545
3	Standoff (1¼")	ST-166-5
3	Standoff (1⅜")	ST-139-10
	Preamp Board Mechanical Parts	
1	Bottom Shield	595-308
1	Standoff (for bottom shield)	ST-26
1	Top Shield	595-305

APPENDIX A

GLOSSARY OF TERMS

Accumulation—The region of bias of a MOS capacitor in which majority carriers are attracted to the Si-SiO_2 interface and accumulate there, forming an accumulation layer. The capacitance of the MOS capacitor in this bias region is essentially that of the oxide capacitor, C_{ox}.

Accuracy—The maximum difference between the actual value of the quantity being measured and the value determined by the instrument. For digital instruments, accuracy is usually specified as a percent of reading plus so many display counts of error.

A/D (Analog-to-Digital) Converter—A device that converts an analog signal into binary or digital values.

Analog—Pertaining to electronic devices in which the output varies as a continuous function of the input.

Analog Output—An output that provides an analog signal proportional to the input signal.

ASCII—Abbreviation for American Standard Code for Information Interchange. A standard code used extensively in computers and data transmission in which 128 letters, numbers, symbols, and special control characters are represented by 7-bit binary numbers.

BASIC—Abbreviation for Beginners All-Purpose Symbolic Instruction Code. A high-level programming language used in many small computers.

Bias Voltage—A voltage level sourced by the instrument for the purpose of biasing the device under test.

Binary—A number system based on the number 2; used extensively in computer-based equipment.

Bit—An abbreviation for binary digit. A unit of binary information is equal to one binary decision, or the designation of one of two possible states, generally represented by 1 and 0.

BNC—A type of coaxial connector used in situations requiring shielded cable for signal connections. (See Low Noise BNC Cable.)

Bus—In computerized equipment, one or more conductors used as a path over which information is transmitted from any of several sources to any of several destinations.

Byte—A group of bits processed together in parallel; by definition a byte is made up of eight bits.

CV Curve—A graph of capacitance versus voltage.

Chassis Ground—A connection to a common metal structure within the instrument. Generally, chassis ground is connected through power line ground to earth ground via a 3-wire power cord for safety purposes.

Coaxial Cable—A cable in which one conductor completely surrounds the other, the two being coaxial and separated by continuous solid dielectric.

Common Mode Voltage—A voltage applied between input low and chassis ground of the instrument.

Controller—A device which governs the operation of the IEEE-488 bus; generally a controller is a small computer or microcomputer.

Conversion—A single piece of binary data that is the result of the A/D converter transformation process. A conversion is one sample.

Count—The minimum increment that an instrument display can resolve. Display size is often defined in counts, as in a 20,000 count display.

DAC—Abbreviation for Digital-to-Analog Converter. A device which converts digital or binary information into an analog signal.

Delay Time—Period of time between when Step V is applied and when the middle of the third charge measurement (Q3) is made (the center of a line cycle conversion). This is user-adjustable.

Depletion—The region of bias of a MOS capacitor in which majority carriers are repelled from the Si-SiO_2 interface, leaving fixed uncompensated acceptor or donor ions, and in which the surface potential does not exceed the bulk potential. In this region, no mobile carriers collect at the Si-SiO_2 interface.

Digital—Circuitry in which the data-carrying signals are restricted to one of two voltage levels. These voltage levels are used to represent the binary values of 1 and 0.

Digital Filter—A method of combining a number of measurement results mathematically to produce a filtered result. The filtered result ideally represents the measured quantity exclusive of noise signals.

Digitize—To convert an analog signal into a series of binary numbers representing its amplitude at discrete intervals of time.

Earth Ground—A connection from an electrical circuit or instrument to the earth through a water pipe or metal rod driven into the ground.

EMI—Abbreviation for Electromagnetic Interference. A term that defines unwanted electromagnetic radiation from a device which could interfere with desired signals in electronic receiving equipment such as television and radio. RFI (Radio Frequency Interference) and EMI are often used interchangeably.

Flat-Band Condition—The bias of a MOS capacitor at which the surface potential is zero, i.e., there is no band bending and carriers are neither attracted to nor repelled from the Si-SiO_2 interface.

GPIB—Abbreviation for General Purpose Interface Bus. Another term for the IEEE-488 bus.

Hexadecimal—A number system based on the number 16 that uses values 0-9, and A through F to represent the 16 possible values of a 4-bit binary number. Hexadecimal numbers are represented by preceding them with a $ or following them with a letter H. Thus, $7F and 7FH would be equivalent.

IC—Abbreviation for Integrated Circuit. A combination of interconnected circuit elements inseparably contained on or within a single substrate.

IEEE-488 Bus—A parallel instrumentation data and control bus standardized by the Institute of Electrical and Electronic Engineers.

I/O—Abbreviation for input/output, which refers to the transmission of information from an instrument to an external device (output), or the transfer of information from an external device to an instrument (input).

Inversion—The region of bias of a MOS capacitor in which majority carriers are repelled from the Si-SiO_2 interface, leaving uncompensated acceptor or donor ions, and in which minority carriers are induced to collect at the interface. In this region, the surface potential exceeds the bulk potential.

k—Abbreviation for kilo. In computer terms, 1K equals 1024. For example, a 16K byte memory has 16,384 bytes.

LED—Light Emitting Diode. A PN junction diode that emits light when forward biased. LEDs are used in front panel annunciators as well as the individual segments of numeric displays on instrumentation.

Leakage Current—Error current that can affect the operation of sensitive instrumentation. Low resistance paths between low current conductors and nearby voltage sources can generate significant error currents.

Line Cycle—The period of one cycle of power line voltage, for instance, 16.66msec for 60Hz power or 20msec for 50Hz power line.

Listener—A device which, when connected to the IEEE-488 bus, is capable of receiving information over that bus.

Low Noise BNC Cable—A BNC cable lubricated with graphite between the braid and inner insulator to reduce the generation of triboelectric currents by vibration or movement.

Measurement Conversion—Measurement of the input which will be used to calculate a reading.

Microprocessor—The control and processing portion of a small computer, microcomputer, or computerized device, which is usually contained within one LSI (Large Scale Integration) IC.

Noise—Any unwanted signal appearing in an electronic device.

Normal Mode Rejection Ratio—The ratio of the output of a circuit to an applied normal mode input. This is typically specified at line frequencies in decibels and is abbreviated NMRR. NMRR is expressed as:

$$\text{NMRR(dB)} = 20 \log \left(\frac{\text{OUTPUT}}{\text{INPUT}} \right) \mid f_{LINE}$$

Normal Mode Voltage—A voltage applied between the input high and input low terminals of an instrument.

Normalization—The ratio of a reading to a previously determined baseline reading. Normalization allows comparison of the shapes of curves with unequal magnitudes. An example of normalization is when a capacitance reading (C) is divided by a stored capacitance reading (C_0). This is the function of the Model 595 C/C_0 feature.

NVRAM—Abbreviation for Non-Volatile Random Access Memory. A special type of electrically alterable ROM that is used to store information such as calibration constants on a semi-permanent basis. Stored information is retained when power is removed from the device, yet may be changed by the digital circuit when desired.

Parallel—The simultaneous storage, transmission, or logical operation on a group of bits at one time.

Peak-to-peak Reading—The most negative sample (least positive) subtracted from the most positive sample in a measurement.

Plotter—A device that produces an inscribed display of the variation of a dependent variable (Y axis) as a function of an independent variable (X axis). When plotting C-V measurements, the Y axis represents capacitance, and the X axis represents voltage.

Programmable Instrument—An instrument whose operation can be determined with commands sent over the IEEE-488 bus.

Q/t—This is a current measurement that is made simultaneously (during the last $^1/_8$ of the delay time or 44msec, whichever is greater) with capacitance measurements. It is used to determine the magnitude of leakage currents (resistive or constant) or non-equilibrium changing currents.

RAM—Abbreviation for Random Access Memory. A type of memory where information can be stored (written) and accessed (read). RAM memory is usually volatile, meaning that data is lost when the power is turned off.

Random Access—Access to any location in instrument memory where each location can be accessed in the same amount of time.

Reading—A processed measurement (for example, filtered, suppressed, or normalized) which is shown on the front panel display or sent over the IEEE-488 bus.

Reading Rate—The rate at which the instrument can display readings. This is user-controllable via the delay time parameter.

Real Time—An operation that is performed as events occur, rather than being stored for subsequent processing.

Resolution—The smallest increment of change that can be detected, indicated or sourced by the instrument.

ROM—Abbreviation for Read Only Memory. A type of memory which permanently stores program information for a microprocessor. ROM memory is non-volatile, which means that programmed information remains intact after power is removed.

Settling Time—The time interval, following the initiation of a specified stimulus to the instrument input, required for the instrument response to reach and maintain a final value within specified limits.

Software—The program instruction coding within an instrument or computer that makes the unit operate.

Square Wave—A cyclic voltage waveform that toggles between two voltages which spends equal time at each voltage.

Staircase—A voltage waveform that begins at a voltage and proceeds one Step V per unit delay time until a limit is reached.

Step V—A voltage increment of a predetermined amount. In the Model 595, Step V is user-selectable from the front panel or the IEEE-488 bus.

Suppress—A feature that allows a baseline measurement to be subtracted from subsequent measurements.

Talker—A device that can transmit information over the IEEE-488 bus.

Trigger—An external stimulus of some sort that initiates one or more measurements.

APPENDIX B

ASCII CHARACTER CODES AND IEEE-488 MULTILINE INTERFACE COMMAND MESSAGES

Decimal	Hexadecimal	ASCII	IEEE-488 Messages*
0	00	NUL	
1	01	SOH	GTL
2	02	STX	
3	03	ETX	
4	04	EOT	SDC
5	05	ENQ	PPC
6	06	ACK	
7	07	BEL	
8	08	BS	GET
9	09	HT	TCT
10	0A	LF	
11	0B	VT	
12	0C	FF	
13	0D	CR	
14	0E	SO	
15	0F	SI	
16	10	DLE	
17	11	DC1	LLO
18	12	DC2	
19	13	DC3	
20	14	DC4	DCL
21	15	NAK	PPU
22	16	SYN	
23	17	ETB	
24	18	CAN	SPE
25	19	EM	SPD
26	1A	SUB	
27	1B	ESC	
28	1C	FS	
29	1D	GS	
30	1E	RS	
31	1F	US	

* Message sent or received with ATN true.

ASCII CHARACTER CODES AND IEEE-488 MULTILINE INTERFACE COMMAND MESSAGES

Decimal	Hexadecimal	ASCII	IEEE-488 Messages*
32	20	SP	MLA 0
33	21	!	MLA 1
34	22	"	MLA 2
35	23	#	MLA 3
36	24	$	MLA 4
37	25	%	MLA 5
38	26	&	MLA 6
39	27	'	MLA 7
40	28	(	MLA 8
41	29	)	MLA 9
42	2A	*	MLA 10
43	2B	+	MLA 11
44	2C	,	MLA 12
45	2D	–	MLA 13
46	2E	.	MLA 14
47	2F	/	MLA 15
48	30	0	MLA 16
49	31	1	MLA 17
50	32	2	MLA 18
51	33	3	MLA 19
52	34	4	MLA 20
53	35	5	MLA 21
54	36	6	MLA 22
55	37	7	MLA 23
56	38	8	MLA 24
57	39	9	MLA 25
58	3A	:	MLA 26
59	3B	;	MLA 27
60	3C	<	MLA 28
61	3D	=	MLA 29
62	3E	>	MLA 30
63	3F	?	UNL

* Message sent or received with ATN true. Numbers shown represent primary address resulting in MLA (My Listen Address).

ASCII CHARACTER CODES AND IEEE-488 MULTILINE INTERFACE COMMAND MESSAGES

Decimal	Hexadecimal	ASCII	IEEE-488 Messages*
64	40	@	MTA 0
65	41	A	MTA 1
66	42	B	MTA 2
67	43	C	MTA 3
68	44	D	MTA 4
69	45	E	MTA 5
70	46	F	MTA 6
71	47	G	MTA 7
72	48	H	MTA 8
73	49	I	MTA 9
74	4A	J	MTA 10
75	4B	K	MTA 11
76	4C	L	MTA 12
77	4D	M	MTA 13
78	4E	N	MTA 14
79	4F	O	MTA 15
80	50	P	MTA 16
81	51	Q	MTA 17
82	52	R	MTA 18
83	53	S	MTA 19
84	54	T	MTA 20
85	55	U	MTA 21
86	56	V	MTA 22
87	57	W	MTA 23
88	58	X	MTA 24
89	59	Y	MTA 25
90	5A	Z	MTA 26
91	5B	[	MTA 27
92	5C	\	MTA 28
93	5D	]	MTA 29
94	5E	∩	MTA 30
95	5F	—	UNT

* Message sent or received with ATN true. Numbers shown are primary address resulting in MTA (My Talk Address).

ASCII CHARACTER CODES AND IEEE-488 MULTILINE INTERFACE COMMAND MESSAGES

Decimal	Hexadecimal	ASCII	IEEE-488 Messages*
96	60	∩	MSA 0,PPE
97	61	a	MSA 1,PPE
98	62	b	MSA 2,PPE
99	63	c	MSA 3,PPE
100	64	d	MSA 4,PPE
101	65	e	MSA 5,PPE
102	66	f	MSA 6,PPE
103	67	g	MSA 7,PPE
104	68	h	MSA 8,PPE
105	69	i	MSA 9,PPE
106	6A	j	MSA 10,PPE
107	6B	k	MSA 11,PPE
108	6C	l	MSA 12,PPE
109	6D	m	MSA 13,PPE
110	6E	n	MSA 14,PPE
111	6F	o	MSA 15,PPE
112	70	p	MSA 16,PPD
113	71	q	MSA 17,PPD
114	72	r	MSA 18,PPD
115	73	s	MSA 19,PPD
116	74	t	MSA 20,PPD
117	75	u	MSA 21,PPD
118	76	v	MSA 22,PPD
119	77	w	MSA 23,PPD
120	78	x	MSA 24,PPD
121	79	y	MSA 25,PPD
122	7A	z	MSA 26,PPD
123	7B	{	MSA 27,PPD
124	7C	|	MSA 28,PPD
125	7D	}	MSA 29,PPD
126	7E	~	MSA 30,PPD
127	7F	DEL	

*Message send or received with ATN true. Numbers represent secondary address values resulting in MSA (My Secondary Address).

APPENDIX C

EQUIVALENT DEVICE-DEPENDENT COMMANDS FOR FRONT PANEL CONTROLS

Operation	Front Panel Control(s)	Equivalent DDC(s)
METER:		
Current function	CURRENT	F1
Capacitance function	CAPACITANCE	F0
Display Q/t	SHIFT CAPACITANCE	Q1, Q3
Correction	Program cCAP *	Q2, Q3
Suppression (on/off)	SUPPRESS	N0, N1
Comparison (on/off)	C/C_0	C0, C1
using new value	SHIFT STORE C_0	C2
Range	RANGE ▲ ▼	R1 - R8
Zero check (on/off)	ZERO CHECK	Z0, Z1
Zero corrected (on)	SHIFT ZERO CHECK	Z2
VOLTAGE SOURCE:		
High limit (adjust)	▲ LIMIT, ADJUST ▲ ▼	Hnn.nn
Low limit (adjust)	▼ LIMIT, ADJUST ▲ ▼	Lnn.nn
Step voltage (adjust)	STEP V, +/−, ADJUST ▲ ▼	S0 - S7
Delay time (adjust)	DELAY TIME	Innn.nn
Voltage source (adjust)	DISPLAY SOURCE, +/−, ADJUST ▲ ▼, PRESET	Vnn.nn
WAVEFORM:		
Voltage source off	SELECT ▲ (OFF)	W0
DC output	SELECT ▲ ▼ (DC)	W1
Square wave output	SELECT ▼ (STEP)	W2
Staircase output	SHIFT STEP V, SELECT ▼ (STEP)	W3
ANALOG OUTPUT:		
Gain and pen control	Program Aout *	O0 - O7

* Front panel programs are selected by pressing PROGRAM MENU until program is displayed.

APPENDIX D

IBM PC/XT and MODEL 8573A PROGRAMMING

INTRODUCTION

This appendix contains general programming information needed to control the Model 595 with the IBM PC/XT personal computer via the Keithley Model 8573A IEEE-488 interface. Refer to the Model 8573A Instruction Manual for complete programming information.

CONTROLLER HANDLER SOFTWARE

Before a specific controller can be used over the IEEE-488 bus, it must have IEEE-488 handler software installed. For the IBM, the necessary handler software is provided on diskette, along with the Model 8573A interface.

INTERFACE BASIC PROGRAMMING STATEMENTS

This section covers the Model 8573A statements that are essential to Model 595 operation. A partial list of programming statements is contained in Table D-1. Each of these statements uses the IBM BASIC CALL statement, with various variables as shown in the table. The command words such as IBCLR (Interface Bus Clear) and IBSRE (Interface Bus Send Remote Enable), are in fact BASIC variables themselves, which must be initialized at the start of each BASIC program.

SOFTWARE CONFIGURATION

Before using the Model 8573A, you must configure the software by using the procedure below. Note that the binary handler file called GPIB.COM and the system configuration file called CONFIG.SYS must be present on the DOS boot disk, as described in the Model 8573A Instruction Manual.

1. Boot up your system in the usual manner and enter BASICA.
2. Place the Model 8573A software disk into the default drive and load the program called "DECL.BAS". Modify the program by changing the XXXXX values in lines 1 and 2 to 16000.
3. Add the following lines to the declaration file:

```
7 NA$="GPIB0":CALL IBFIND(NA$,BRD0%)
8 NA$="DEV0":CALL IBFIND(NA$,M595%)
9 V%=28:CALL IBPAD(M595%,V%)
```

4. Now type in your BASIC program starting at line 10. Standard BASIC statements as well as calls from Table D-1 may be used. See the Model 8573A Instruction Manual for a full list of the call statements and their proper use.

An example program using the IBM PC/XT and the Model 8573A can be found in Appendix E.

Table D-1. BASIC Statements Necessary to Send Bus Commands

Action	Model 8573A Statement
Transmit string to device 28.	CALL IBWRT (M595%, CMD$)
Obtain string from device 28.	CALL IBRD (M595%, RD$)
Send GTL to device 28.	CALL IBLOC (M595%)
Send SDC to device 28.	CALL IBCLR (M595%)
Send DCL to all devices.	CMD$=CHR$ (&H14): CALL IBCMD (BRD0%, CMD$)
Send remote enable.	V%=1: CALL IBSRE (BRD0%, V%)
Cancel remote enable.	V%=0: CALL IBSRE (BRD0%, V%)
Serial poll device 28.	CALL IBRSP (M595%, SB%)
Send local lockout.	CMD$=CHR$ (&H11): CALL IBCMD (BRD0%, CMD$)
Send GET to device.	CALL IBTRG (M595%)
Send IFC.	CALL IBSRE (BRD0%)

APPENDIX E

CONTROLLER PROGRAMS

The following programs have been supplied as a simple aid to the user and are not intended to suit specific needs. Each program allows you send a device-dependent command string to the instrument and obtain and display an instrument reading string.

Programs for the following controllers are included:

- IBM PC or XT (with Keithley Model 8573A IEEE-488 Interface)
- Apple II (equipped with the Apple II IEEE-488 Interface)
- Hewlett-Packard Model 85
- Hewlett-Packard Model 9816
- Hewlett-Packard Model 9825A
- DEC LSI 11
- PET/CBM 2001

IBM PC OR XT (KEITHLEY MODEL 8573A INTERFACE)

The following program sends a command string to the Model 595 from an IBM PC or XT computer and displays the instrument reading string on the CRT. The computer must be equipped with the Keithley Model 8573A IEEE-488 Interface and the DOS 2.00 operating system. Model 8573A software must be installed and configured as described in the instruction manual.

DIRECTIONS

1. Using the front panel program feature, set the primary address of the Model 595 to 28.
2. With the power off, connect the Model 595 to the IEEE-488 interface installed in the IBM computer.
3. Type in BASICA on the computer keyboard to get into the IBM interpretive BASIC language.
4. Place the interface software disk in the default drive, type LOAD"DECL", and press the return key.
5. Add the lines below to lines 1-6 which are now in memory. Modify the address in lines 1 and 2, as described in the Model 8573A Instruction Manual.
6. Run the program and type in the desired command string. For example, to place the instrument in the current function and 200μA range, type in F1R8X and press the return key.
7. The instrument reading string will then appear on the display. For example, the display might show NIVX+0.59500E−4, +000.00.
8. To exit the program, type in EXIT at the command prompt and press the return key.

PROGRAM	COMMENTS
`10 CLS`	Clear screen.
`20 NA$="GPIB0":CALL IBFIND (NA$,BRD0%)`	Find board descriptor.
`30 NA$="DEV1":CALL IBFIND (NA$,M595%)`	Find instrument descriptor.
`40 V%=28:CALL IBPAD(M595%,V%)`	Set primary address to 28.
`50 V%=&H102:CALL IBPOKE(BRD0%,V%)`	Set timeouts.
`60 V%=1:CALL IBSRE(BRD0%,V%)`	Set REN true.
`70 INPUT"COMMAND STRING";CMD$`	Prompt for command.
`80 IF CMD$="EXIT" THEN 150`	See if program is to be halted.
`90 IF CMD$="" THEN 70`	Check for null input.
`100 CALL IBWRT(M595%,CMD$)`	Address 595 to listen, send string.
`110 RD$=SPACE$(100)`	Define reading input buffer.
`120 CALL IBRD(M595%,RD$)`	Address 595 to talk, get reading.
`130 PRINT RD$`	Display the string.
`140 GOTO 70`	Repeat.
`150 V%=0:CALL IBONL(M595%,V%)`	Close the instrument file.
`160 CALL IBONL(BRD0%, V%)`	Close the board file.
`170 END`	

NOTE: For conversion to numeric variable, make the following changes:

```
130 RD=VAL(MID$(RD$,5,14))
135 PRINT RD
```

APPLE II (APPLE II IEEE-488 INTERFACE)

The following program sends a command string to the Model 595 from an Apple II computer and displays the instrument reading string on the computer CRT.

The computer must be equipped with the Apple II IEEE-488 Interface installed in slot 3.

DIRECTIONS

1. Using the front panel program feature, set the primary address of the Model 595 to 28.
2. With the power off, connect the Model 595 to the IEEE-488 interface installed in the Apple II computer.
3. Enter the lines in the program below, using the RETURN key after each line.
4. Run the program and type in the desired command string at the command prompt. For example, to place the instrument in the current function and 200μA range, type in F1R8X and press the return key.
5. The instrument reading string will then appear on the CRT. A typical display is: NIVX+0.59500E−4, +00.000.

PROGRAM	COMMENTS
`10 Z$=CHR$(26)`	Terminator.
`20 INPUT''COMMAND STRING'';B$`	Prompt for and enter string.
`30 PR#3`	Set output to IEEE bus.
`40 IN#3`	Define input from IEEE bus.
`60 PRINT''WT<'';Z$;B$`	Address 595 to listen, send string.
`70 PRINT''LF1''`	Line Feed on.
`80 PRINT''RD'';CHR$(92);Z$`	
`81 A$='' '':C$='' ''`	Strings initially empty.
`82 GET A$`	Read a character.
`83 PRINT A$`	Echo (display) a character.
`84 IF ASC (A$)=13 THEN GOTO 90`	End of input if CR.
`85 C$=C$+A$`	Add characters to string.
`86 GOTO 82`	
`90 PRINT''UT''`	Untalk the 595.
`100 PR#0`	Define output to CRT.
`110 IN#0`	Define input from keyboard.
`120 PRINT C$`	Display reading string.
`130 GOTO 20`	Repeat.

NOTES:

1. If conversion to numeric variable is required, make the following changes:

```
120 C=VAL(MID$(C$,5,14))
125 PRINT C
```

2. The Apple II INPUT statement terminates on commas.

HEWLETT-PACKARD MODEL 85

The following program sends a command string to the Model 595 from an HP-85 computer and displays the instrument reading string on the computer CRT. The computer must be equipped with the HP82937 GPIB Interface and an I/O ROM.

DIRECTIONS

1. Using the front panel program feature, set the primary address of the Model 595 to 28.
2. With the power off, connect the Model 595 to the HP82937A GPIB interface installed in the HP-85 computer.
3. Enter the lines in the program below, using the END LINE key after each line.
4. Press the HP-85 RUN key and type in the desired command string at the command prompt. For example, to place the instrument in the current function and 200μA range, type in F1R8X and press the END LINE key.
5. The instrument reading string will then appear on the CRT. A typical display is: NIVX+0.59500E−4, +00.000.

PROGRAM	COMMENTS
`10 DIM A$[40],B$[40]`	Dimension strings.
`20 REMOTE 728`	Place 595 in remote.
`30 DISP''COMMAND STRING'';`	Prompt for command.
`40 INPUT A$`	Input command string.
`50 OUTPUT 728; A$`	Address 595 to listen, send string.
`60 ENTER 728; B$`	Address 595 to talk, input reading.
`70 DISP B$`	Display reading string.
`80 GOTO 30`	Repeat
`90 END`	

NOTE: For conversion to numeric variable, change line 70 as follows:

```
70 DISP VAL(B$[3])
```

HEWLETT-PACKARD MODEL 9816

The following program sends a command string to the Model 595 from a Hewlett-Packard Model 9816 computer and displays the instrument reading string on the computer CRT. The computer must be equipped with the HP82937 GPIB Interface and BASICA 2.0.

DIRECTIONS

1. Using the front panel program feature, set the primary address of the Model 595 to 28.
2. With the power off, connect the Model 595 to the HP82937A GPIB interface installed in the 9816 computer.
3. Type EDIT and press the EXEC key.
4. Enter the lines in the program below, using the ENTER key after each line.
5. Press the 9816 RUN key and type in the desired command string at the command prompt. For example, to place the instrument in the current function and 200μA range, type in F1R8X and press the ENTER key.
6. The instrument reading string will then appear on the CRT. A typical display is: NIVX+0.59500E−4, +00.000.

PROGRAM	COMMENTS
`5 DIM B$[50]`	
`10 REMOTE 728`	Place 595 in remote.
`20 INPUT''COMMAND STRING'';A$`	Prompt for and input command.
`30 OUTPUT 728; A$`	Address 595 to listen, send string.
`40 ENTER 728; B$`	Address 595 to talk, input reading.
`50 PRINT B$`	Display reading string.
`60 GOTO 20`	Repeat.
`70 END`	

NOTE: For conversion to a numeric variable, change the program as follows:

```
40 ENTER 728;B
50 PRINT B
```

HEWLETT-PACKARD MODEL 9825A

Use the following program to send a command string to the Model 595 from a Hewlett-Packard Model 9825A and display the instrument reading string on the computer printer. The computer must be equipped with the HP98034A HPIB Interface and a 9872A extended I/O ROM.

DIRECTIONS

1. From the front panel, set the primary address of the Model 595 to 28.
2. With the power off, connect the Model 595 to the 98034A HPIB interface installed in the 9825A.
3. Enter the lines in the program below, using the STORE key after each line. Line numbers are automatically assigned by the 9825A.
4. Press the 9825A RUN key and type in the desired command string at the command prompt. For example, to place the instrument in the current function and 200μA range, type in F1R8X and press the CONT key.
5. The instrument reading string will then appear on the computer print out. A typical display is: NIVX+0.59500E−4, +000.00.

PROGRAM	COMMENTS
`0 dim A$[25],B$[20]`	Dimension data strings.
`1 dev''595'',728`	Define 595 at address 28.
`2 rem''595''`	Place 595 in remote.
`3 ent''COMMAND STRING'',B$`	Prompt for command string.
`4 wrt''595'',B$`	Address 595 to listen, send string.
`5 red''595'',A$`	Address 595 to talk, input data.
`6 prt A$`	Print data string on printer.
`7 gto 3`	Repeat.

NOTE: For conversion to numeric variable, modify the program as follows:

```
6 prt val(A$[5])
```

DEC LSI 11

The following program sends a command string to the Model 595 from a DEC LSI 11 minicomputer and displays the instrument reading string on the DEC CRT terminal. The LSI 11 must be configured with 16K words of RAM and an IBV 11 IEEE-488 interface. The software must be configured with the IB software as well as FORTRAN and the RT 11 operating system.

DIRECTIONS

1. Using the front panel program feature, set the primary address of the Model 595 to 28.
2. With the power off, connect the Model 595 to the IBV 11 IEEE-488 interface cable.
3. Enter the program below, using the editor under RT 11 and the name IEEE.FOR.
4. Compile using the FORTRAN compiler as follows: FORTRAN IEEE.
5. Link with the system and IB libraries as follows: LINK IEEE,IBLIB.
6. Type RUN IEEE and press the RETURN key.
7. The display will read "ENTER ADDRESS".
8. Type in 9 and press the RETURN key.
9. The display will read "TEST SETUP".
10. Type in the desired command string and press the RETURN key. For example, to program the instrument for the current function and 200μA range, type in F1R8X and press RETURN.
11. The instrument data string will appear on the computer display. A typical display is: NIVX+0.59500E−12, +000.00.

PROGRAM	COMMENTS
`PROGRAM IEEE`	
`INTEGER*2 PRIADR`	
`LOGICAL*1 MSG(80),INPUT(80)`	
`DO 2 I = 1,10`	
`CALL IBSTER(I,0)`	Turn off IB errors.
`2 CONTINUE`	
`CALL IBSTER(15,5)`	Allow 5 error 15's.
`CALL IBTIMO(120)`	Allow 1 second bus timeout.
`CALL IBTERM(10)`	Set line feed as terminator.
`CALL IBREN`	Turn on remote.
`4 TYPE 5`	
`5 FORMAT (1X,'ENTER ADDRESS:',$)`	Input primary address.
`ACCEPT 10,PRIADR`	
`10 FORMAT (I2)`	
`12 TYPE 15`	
`15 FORMAT (1X,'TEST SETUP:',$)`	Prompt for command string.
`CALL GETSTR (5,MSG,72)`	Program instrument.
`CALL IBSEOI (MSG,-1,PRIADR)`	Address 595 to listen, send string.
`18 I=IBRECV (INPUT,80,PRIADR)`	Get data from instrument.
`INPUT (I+1) = 0`	
`CALL PUTSTR (7,INPUT,'0')`	
`CALL IBUNT`	Untalk the 595.
`GOTO 12`	Repeat.
`END`	

PET/CBM 2001

The following program sends a command string to the Model 595 from a PET/CBM 2001 computer and displays the instrument reading string on the computer CRT. As the PET/CBM computer has a standard IEEE-488 interface, no additional equipment is necessary.

DIRECTIONS

1. Using the front panel program feature, set the primary address of the Model 595 to 28.
2. With the power off, connect the Model 595 to the PET/CBM IEEE-488 interface.
3. Enter the lines of the program below, using the RETURN key after each line is typed.
4. Type RUN and press the RETURN key. Type in the desired command string at the command prompt. For example, to place the instrument in the current function and 200μA range, type in F1R8X and press the RETURN key.
5. The instrument reading string will then appear on the CRT. A typical display is: NIVX+0.59500E−12, +000.00.

PROGRAM	COMMENTS
`10 OPEN 1,28`	Open file 1, primary address 28.
`20 INPUT''COMMAND STRING'';B$`	Prompt for, input command string.
`30 PRINT#1,B$`	Address 595 to listen, send string.
`40 INPUT#1,A$`	Address 595 to talk, input data.
`50 IF ST = 2 THEN 40`	If bus timeout, input again.
`60 PRINT A$`	Display reading string.
`70 GOTO 20`	Repeat.

NOTES:

1. If conversion to numeric variable is required, modify the program as follows:

```
60 A = VAL(MID$(A$,5,14))
70 PRINT A
80 GOTO 20
```

2. The PET INPUT# statement terminates on a comma. Thus, when reading Model 595 command strings which include commas, you should input each portion of the string into a separate string variable. For example, in the G2 (default) mode, to obtain and display the channel number, the program above can be modified as follows:

```
40 INPUT#1, A$,C$
60 PRINT A$",";C$
```

APPENDIX F

IEEE-488 BUS OVERVIEW

BUS DESCRIPTION

The IEEE-488 bus, which is also frequently referred to as the GPIB (General Purpose Interface Bus), was designed as a parallel transfer medium to optimize data transfer with a minimum number of bus lines. In keeping with this goal, the bus has eight data lines that are used both for data and many commands. Additionally, the bus has five management lines, which are used to control bus operation, and three handshake lines that are used to control the data byte transfer sequence.

A typical configuration for controlled bus operation is shown in Figure F-1. A typical system will have one controller and one or more devices to which commands are given and, in most cases, from which data is received. Generally, there are three categories that describe device operation: controller, talker, and listener.

The controller does what its name implies: it controls other devices on the bus. A talker sends data (usually to the controller), and a listener receives data. Depending on the instrument, a particular device may be a talker only, a listener only, or both a talker and a listener. The Model 595 has both talker and listener capabilities.

There are two categories of controllers: system controller and basic controller. Both are able to control other devices, but only the system controller has absolute authority in the system. In a system with more than one controller, only one controller may be active at any given time. Certain command protocol allows control to be passed from one controller to another.

The bus is limited to 15 devices, including the controller. Thus, any number of devices may be present on the bus at one time. Although several active listeners may be present simultaneously, only one active talker may be present on the bus, or communications would be scrambled.

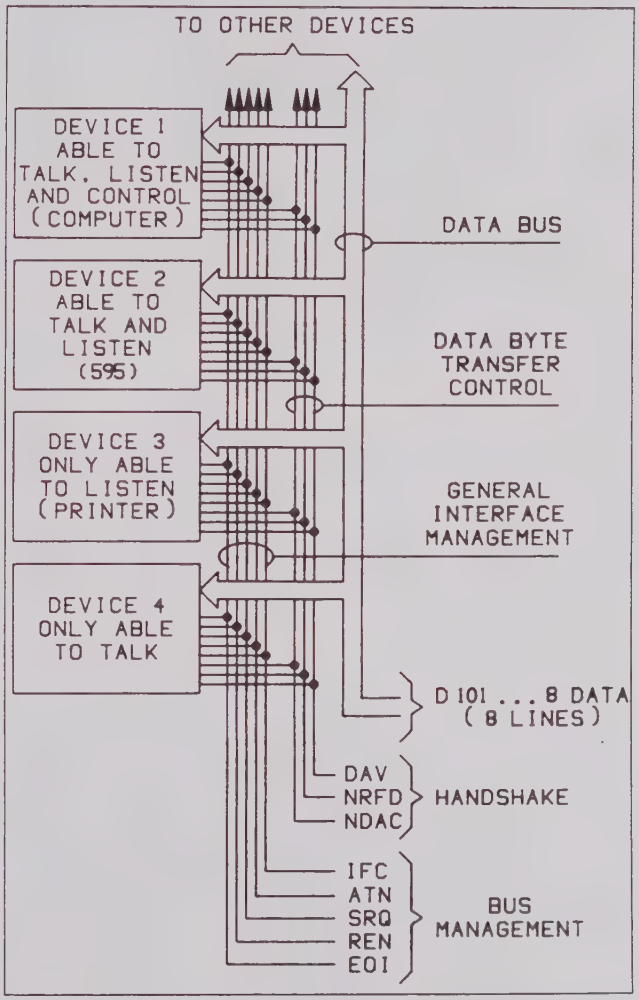


Figure F-1. IEEE Bus Configuration

A device is placed in the talk or listen mode from the controller by sending an appropriate talk or listen command. These talk and listen commands are derived from an instrument's primary address. The primary address may have any value between 0 and 30 and is generally set by rear panel switches or programmed in from the front panel (as in the case of the Model 595). The actual listen command value sent over the bus is derived by ORing the primary address with $20 (the $ symbol preceding the number designates a hexadecimal, or base 16 value). For example, if the primary address is 28 (the default Model 595 value), the actual listen command byte value is $3C ($1C + $20 = $3C). In a similar manner, the talk command byte is derived by ORing the primary address with $40. With a primary address of 28, the actual talk command byte would be $5C ($40 + $1C = $5C).

The IEEE-488 standards also include another addressing mode called secondary addressing. Secondary address byte values lie in the range of $60-$7F. Note, however, that many devices, including the Model 595, do not use secondary addressing.

Once the device is properly addressed, bus transmission sequences are set to take place. For example, if an instrument is addressed to talk, it will usually output its data string on the bus one byte at a time. The listening device (frequently the controller) will then read this information as transmitted.

BUS LINES

The signal lines on the IEEE-488 bus are grouped into three categories: data lines, management lines, and handshake lines. The eight data lines handle bus data and many commands, while the management and handshake lines ensure orderly bus operation. Each bus line is active low with approximately zero volts representing logic 1 (true). The following paragraphs briefly describe the operation of these lines.

Data Lines

The bus uses eight data lines to transmit and receive data in bit-parallel, byte serial fashion. These lines use the convention DIO1-DIO8 instead of the more common D0-D7. DIO1 is the least significant bit, while DIO8 is the most significant bit. The data lines are bidirectional (with most devices), and, as with the remaining bus lines, low is considered to be true.

Bus Management Lines

The five bus management lines ensure proper interface control and management. These lines are used to send uniline commands.

ATN (Attention)—The state of ATN determines how information on the data lines is to be interpreted.

IFC (Interface Clear)—IFC allows the clearing of active talkers or listeners from the bus.

REN (Remote Enable)—REN is used to place devices in the remote mode. Usually, devices must be in remote before they can be programmed over the bus.

EOI (End Or Identify)—EOI is used to mark the end of a multi-byte data transfer sequence. EOI is also used along with ATN, to send the IDY (identify) message for parallel polling.

SRQ (Service Request)—SRQ is used by devices to request service from the controller.

Handshake Lines

Three handshake lines that operate in an interlocked sequence are used to ensure reliable data transmission regardless of the transfer rate. Generally, data transfer will occur at a rate determined by the slowest active device on the bus. These handshake lines are:

DAV (Data Valid)—The source (talker) controls the state of DAV to indicate to any listeners when data is valid.

NRFD (Not Ready For Data)—The acceptor (listener) controls the state of NRFD. It is used to signal the transmitting device to hold off the byte transfer sequence until the accepting device is ready.

NDAC (Not Data Accepted)—NDAC is also controlled by the accepting device. The state of NDAC tells the source whether or not the device has accepted the data byte.

Figure F-2 shows the basic handshake sequence for the transmission of one data byte. This sequence is used to transfer data, talk and listen addresses, as well as multiline commands.

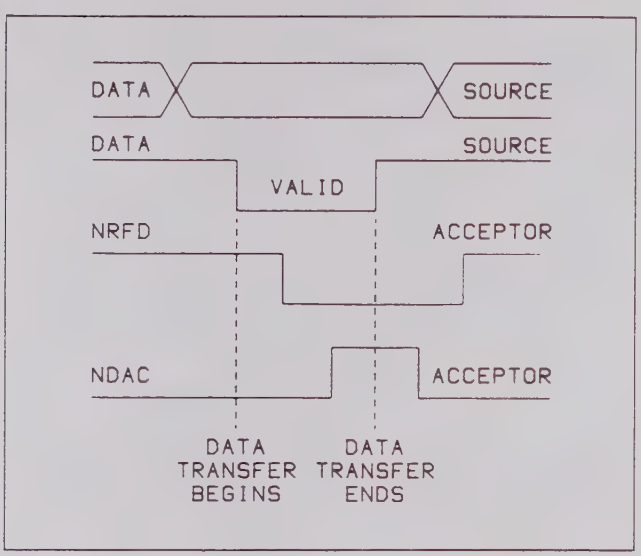


Figure F-2. IEEE-488 Handshake Sequence

BUS COMMANDS

Commands associated with the IEEE-488 bus can be grouped into the following three general categories. Refer to Table F-1.

Uniline Commands—These commands are asserted by setting the associated bus line true. For example, to assert REN (Remote Enable), the REN line would be set low (true).

Multiline Commands—General bus commands which are sent over the data lines with the ATN line true.

Device-dependent Commands—Commands whose meanings depend on the device in question. These commands are transmitted via the data lines while ATN is false.

Table F-1. IEEE-488 Bus Command Summary

Command Type	Command	State of ATN Line*	Comments
Uniline	REN (Remote Enable)	X	Sets up devices for remote operation.
	EOI	X	Marks end of transmission.
	IFC (Interface Clear)	X	Clears interface.
	ATN (Attention)	Low	Defines data bus contents.
	SRQ	X	Controlled by external device.
Multiline			
Universal	LLO (Local Lockout)	Low	Locks out local operation.
	DCL (Device Clear)	Low	Returns device to default conditions.
	SPE (Serial Enable)	Low	Enables serial polling.
	SPD Serial Poll Disable)	Low	Disables serial polling.
Addressed	SDC (selective Device Clear)	Low	Returns unit to default conditions.
	GTL (Go To Local)	Low	Returns device to local.
	GET (Group Execute Trigger)	Low	Triggers device for reading.
Unaddressed	UNL (Unlisten)	Low	Removes all listeners from bus.
	UNT (Untalk)	Low	Removes any talkers from bus.
Device-dependent		High	Programs Model 595 for various modes.

*Don't Care.

Uniline Commands

The five uniline commands include REN, EOI, IFC, ATN, and SRQ. Each command is associated with a dedicated bus line, which is set low to assert the command in question.

REN (Remote Enable)—REN is asserted by the controller to set up instruments on the bus for remote operation. When REN is true, devices will be removed from the local mode. Depending on device configuration, all front panel controls except the LOCAL button (if the device is so equipped) may be locked out when REN is true. Generally, REN should be asserted before attempting to program instruments over the bus.

EOI (End or Identify)—EOI may be asserted either by the controller or by external devices to identify the last byte in a multi-byte transfer sequence, allowing data words of various lengths to be transmitted.

IFC (Interface Clear)—IFC is asserted by the controller to clear the interface and return all devices to the talker and listener idle states.

ATN (Attention)—The controller asserts ATN while sending addresses or multiline commands.

SRQ (Service Request)—SRQ is asserted by a device on the bus when it requires service from the controller.

Universal Multiline Commands

Universal multiline commands are those commands that required no addressing as part of the command sequence. All devices equipped to implement these commands will do so simultaneously when the commands are transmitted. As with all multiline commands, these commands are transmitted with ATN true.

LLO (Local Lockout)—LLO is sent to instruments to lock out front panel or local operation of the instrument.

DCL (Device Clear)—DCL is used to return instruments to some default state. Usually, devices return to their power-up conditions.

SPE (Serial Poll Enable)—SPE is the first step in the serial polling sequence, which is used to determine which device on the bus is requesting service.

SPD (Serial Poll Disable)—SPD is used by the controller to remove all devices on the bus from the serial poll mode and is generally the last command in the serial polling sequence.

Addressed Multiline Commands

Addressed multiline commands are those commands that must be preceded by an appropriate listen address before the instrument will respond to the command in question. Note that only the addressed device will respond to the command. Both the command and the address preceding it are sent with ATN true.

SDC (Selective Device Clear)—The SDC command performs essentially the same function as DCL except that only the addressed device responds. Generally, instruments return to their power-up default conditions when responding to SDC.

GTL (Go To Local)—GTL is used to remove instruments from the remote mode and place them in local. With many instruments, GTL may also restore operation of front panel controls if previously locked out.

GET (Group Execute Trigger)—GET is used to trigger devices to perform a specific action that will depend on device configuration (for example, perform a measurement sequence). Although GET is an addressed command, many devices may respond to GET without addressing.

Address Commands

Addressed commands include two primary command groups, and a secondary address group. ATN is true when these commands are asserted. These commands include:

LAG (Listen Address Group)—These listen commands are derived from an instrument's primary address and are used to address devices to listen. The actual command byte is obtained by ORing the primary address with $20.

TAG (Talk Address Group)—The talk commands are derived from the primary address by ORing the address with $40. Talk commands are used to address devices to talk.

SCG (Secondary Command Group)—Commands in this group provide additional addressing capabilities. Many devices (including the Model 595) do not use these commands.

Unaddress Commands

The two unaddress commands are used by the controller to remove any talkers or listeners from the bus. ATN is true when these commands are asserted.

UNL (Unlisten)—Listeners are placed in the listener idle state by UNL.

UNT (Untalk)—Any previously commanded talkers will be placed in the talker idle state by UNT.

Device-Dependent Commands

The purpose of device-dependent commands will depend on instrument configuration. Generally, these commands are sent as one or more ASCII characters that command the device to perform a specific action. For example, the command string R1X is used to control the measurement range of the Model 595.

The IEEE-488 bus treats these commands as data in that ATN is false when the commands are transmitted.

Command Codes

Command codes for the various commands that use the data lines are summarized in Figure F-3. Hexadecimal and and decimal values for the various commands are listed in Table F-2.

D_7 D_6 D_5 D_4					X 0 0 0		X 0 0 1		X 0 1 0		X 0 1 1		X 1 0 0		X 1 0 1		X 1 1 0		X 1 1 1	
BITS D_3 ↓	D_2 ↓	D_1 ↓	D_0 ↓	COLUMN→ ROW↓	0(A)	0(B)	1(A)	1(B)	2(A)	2(B)	3(A)	3(B)	4(A)	4(B)	5(A)	5(B)	6(A)	6(B)	7(A)	7(B)
0	0	0	0	0	NUL		DLE		SP	0	0	16	@	O	P	16			p	
0	0	0	1	1	SOH	GTL	DC1	LLO	!	1	1	17	A	1	Q	17	a		q	
0	0	1	0	2	STX		DC2		"	2	2	18	B	2	R	18	b		r	
0	0	1	1	3	ETX		DC3		#	3	3	19	C	3	S	19	c		s	
0	1	0	0	4	EOT	SDC	DC4	DCL	$	4	4	20	D	4	T	20	d		t	
0	1	0	0	5	ENQ	PPC*	NAK	PPU*	%	5	5	21	E	5	U	21	e		u	
0	1	1	0	6	ACK		SYN		&	6	6	22	F	6	V	22	f		v	
0	1	1	1	7	BEL		ETB		'	7	7	23	G	7	W	23	g		w	
1	0	0	0	8	BS	GET	CAN	SPE	(	8	8	24	H	8	X	24	h		x	
1	0	0	1	9	HT	TCT*	EM	SPD	)	9	9	25	I	9	Y	25	i		y	
1	0	1	0	10	LF		SUB		*	10	:	26	J	10	Z	26	j		z	
1	0	1	1	11	VT		ESC		+	11	;	27	K	11	[	27	k		{	
1	1	0	0	12	FF		FS		,	12	<	28	L	12	\	28	l		:	
1	1	0	1	13	CR		GS		-	13	=	29	M	13	]	29	m		}	
1	1	1	0	14	SO		RS		.	14	>	30	N	14	∩	30	n		~	
1	1	1	1	15	SI		US		/	15	?	UNL	O	15	←	UNT	o		DEL	

ADDRESSED COMMAND GROUP (ACG)

UNIVERSAL COMMAND GROUP (UCG)

LISTEN ADDRESS GROUP (LAG)

TALK ADDRESS GROUP (TAG)

PRIMARY COMMAND GROUP (PCG)

SECONDARY COMMAND GROUP SDC)

*PPC (PARALLEL POLL CONFIGURE). PPU (PARALLEL POLL UNCONFIGURE), AND TCT (TAKE CONTROL) NOT IMPLEMENTED BY MODEL 595.

NOTE: D_0 = DIO1 ... D_7 = DIO8
X = DON'T CARE

Figure F-3. Command Codes

Table F-2. Hexadecimal and Decimal Command Codes

Command	Hex Value	Decimal Value
GTL	01	1
SDC	04	4
GET	08	8
LLO	11	17
DCL	14	20
SPE	18	24
SPD	19	25
LAG	20-3F	32-63
TAG	40-5F	64-95
SGG	60-7F	96-127
UNL	3F	63
UNT	5F	95

Typical Command Sequences

For the various multiline commands, a specific bus sequence must take place to properly send the command. In particular, the correct listen address must be sent to the instrument before it will respond to addressed commands. Table F3 lists a typical bus sequence for sending an addressed multiline command. In this instance, the SDC command is being sent to the instrument. UNL is generally sent as part of the sequence to ensure that no other active listeners are present. Note that ATN is true for both the listen command and the SDC command byte itself.

Table F-3. Typical Addressed Command Sequence

Step	Command	ATN State	Data Bus		
			ASCII	Hex	Decimal
1	UNL	Set low	?	3F	63
2	LAG*	Stays low	<	3C	60
3	SDC	Stays low	EOT	04	4
4		Returns high			

*Assumes primary address = 28.

Table F-4 gives a typical device-dependent command sequence. In this instance, ATN is true while the instrument is being addressed, but it is set high while sending the device-dependent command string.

Table F-4. Typical Device-Dependent Command Sequence

Step	Command	ATN State	Data Bus		
			ASCII	Hex	Decimal
1	UNL	Set low	?	3F	63
2	LAG*	Stays low	<	3C	60
3	Data	Set high	F	52	82
4	Data	Stays high	0	30	48
5	Data	Stays high	X	46	70

*Assumes primary address = 28.

IEEE Command Groups

Command groups supported by the Model 595 are listed in Table F-5. Device-dependent commands are not included in this list.

Table F-5. IEEE Command Group

HANDSHAKE COMMAND GROUP
DAC=DATA ACCEPTED
RFD=READY FOR DATA
DAV=DATA VALID

UNIVERSAL COMMAND GROUP
ATN=ATTENTION
DCL=DEVICE CLEAR
IFC=INTERFACE CLEAR
LLO=LOCAL LOCKOUT
REN=REMOTE ENABLE
SPD=SERIAL POLL DISABLE
SPE=SERIAL POLL ENABLE

ADDRESS COMMAND GROUN
LISTEN: LAG=LISTEN ADDRESS GROUP
MLA=MY LISTEN ADDRESS
UNL=UNLISTEN
TALK: TAG=TALK ADDRESS GROUP
MTA=MY TALK ADDRESS
UNT=UNTALK
OTA=OTHER TALK ADDRESS

ADDRESSED COMMAND GROUP
ACG=ADDRESSED COMMAND GROUP
GET=GROUP EXECUTE TRIGGER
GTL=GO TO LOCAL
SDC=SELECTIVE CLEAR

STATUS COMMAND GROUP
RQS=REQUEST SERVICE
SRQ=SERIAL POLL REQUEST
STB=STATUS BYTE
EOI=END

Device-Dependent Command Summary

Mode	Command	Description
Execute	X	Execute device-dependent commands received since last "X"
METER BLOCK COMMANDS		
Display	D0* D1 D2 D3 D4 D5	Meter Voltage source High limit of voltage source Low limit of voltage source Step voltage Delay time
Function†	F0* F1	Capacitance Current
Range†	 R1 R2 R3* R4 R5 R6 R7 R8	Capacitance (F0) Current (F1) 200pF 20pA 2nF 200pA 20nF 2nA 20nA 200nA 2μA 20μA 200μA
Zero Check†	Z0 Z1* Z2	Zero check off Zero check on Zero check on and zero corrected
Suppress	N0* N1	Suppress off Suppress on using new value
Filter†	P0* P1 P2 P3	Filter off Filter 1 Filter 2 Filter 3 (DC measurements)
VOLTAGE SOURCE COMMANDS		
High Limit†	Hnn.nn H20*	Set high limit of voltage source; where nn.nn = −20.00V to 20.00V
Low Limit†	Lnn.nn L−20*	Set low limit of voltage source; where nn.nn = −20.00V to 20.00V
Voltage Source†	Vnn.nn V0*	Set voltage source bias level; where nn.nn = LO value to HI value
Step Voltage†	S0 S1 S2* S3 S4 S5 S6 S7	10mV step 20mV step 50mV step 100mV step −10mV step −20mV step −50mV step −100mV step

Device-Dependent Command Summary (Cont.)

Mode	Command	Description
Delay Time†	Innn.nn I.07*	Set delay time for staircase and square wave; where nnn.nn = 000.07sec to 199.99sec
WAVEFORM COMMANDS		
Waveform	W0 W1 W2* W3	Voltage source off (0.0 volts) DC output (voltage source level) Square-wave output (voltage source + Vstep) Staircase output (voltage source + Vstep)
READING/OUTPUT COMMANDS		
$\Delta C/C_o$	C0* C1 C2	Capacitance normalization off Capacitance normalization on Take new C_o value
Capacitance Modifiers‡	Q0* Q1 Q2 Q3	Capacitance displayed, not corrected Q/t displayed, capacitance not corrected Capacitance displayed, capacitance corrected Q/t displayed, capacitance corrected
Prefixes		TERMINATE ON EACH READING
	G0 G1 G2 G3	0 = Reading; prefix 1 = Reading; no prefix 2 = Plotter; prefix 3 = Plotter; no prefix
		TERMINATE ON EACH NON-STAIRCASE READING
	G4 G5 G6 G7	4 = Reading; prefix 5 = Reading; no prefix 6 = Plotter; prefix 7 = Plotter; no prefix
Analog Output	O0* O1 O2 O3 O4 O5 O6 O7	Autopen, X1 gain Pen up, X1 gain Pen down, X1 gain Same as O1 Autopen, X10 gain Pen up, X10 gain Pen down, X10 gain Same as O4
BUS CONTROL COMMANDS		
Triggers†	T0 T1 T2 T3 T4 T5 T6* T7	Continuous, triggered by Talk One-shot, triggered by Talk Continuous, triggered by GET One-shot, triggered by GET Continuous, triggered by X One-shot, triggered by X Continuous, triggered by External Trigger One-shot, triggered by External Trigger

Device-Dependent Command Summary (Cont.)

Mode	Command	Description
SRQ Mask	M0*	Clear SRQ mask
	M1	Reading overflow
	M2	Not used
	M4	Staircase done
	M8	Reading done
	M16	Ready
	M32	Error
EOI and Bus Hold-off	K0*	Send EOI, hold off on X
	K1	Do not send EOI, hold off on X
	K2	Send EOI, do not hold off on X
	K3	Do not send EOI, do not hold off on X
Terminator	Y0*	CR LF
	Y1	LF CR
	Y2	CR
	Y3	LF
	Y4	No terminator
STATUS COMMANDS		
Digital Calibration	Annn.nnE-nn	Calibration value using exponent
Self-Test and NVRAM Storage	J0	Perform self-test
	J1-J18	No operation
	J19	Store calibration constants in permanent memory
Status	U0	Send machine status word
	U1	Send error status word
	U2	Send data status word
	U3	Send delay time
	U4	Send high and low limits of voltage source
	U5	Send voltage source level

* DEFAULT VALUE (on power up or after receiving DCL or SDC command)

† If in staircase, waveform will change to DC (pause)

‡ Only changing capacitance correction will cause waveform to change to DC.

Note: If a measurement is changed to DC, the output voltage is moved to the next level where the effective step is off in order to preserve the direction of the measurement.

APPENDIX H

MODEL 595 IEEE-488 PLOTTING COMMANDS

INTRODUCTION

This appendix includes the bus commands and information sequences sent from the Model 595 when plotting with an HPGL-compatible digital plotter (or printing with an IEEE-488 compatible printer).

IEEE-488 CODES

These codes are selected via the front panel IEEE-488 address program.

40 - Printer, prefix
41 - Printer, no prefix
42 - Plotter, standard X axis
43 - Plotter, reverse X axis

BUS COMMANDS

The following bus commands are sent when the Model 595 is set to IEEE-488 codes 40 to 43:

40 - IFC REN UNL MTA(00) LAG(3) CR LF DATA
41 - IFC REN UNL MTA(00) LAG(3) CR LF DATA
42 - IFC REN
43 - IFC REN

DEVICE-DEPENDENT COMMANDS

Device-dependent commands G (Prefix), K (EOI), and Y(Terminator) will be changed to the following values when the Model 595 is set to IEEE-488 codes 40 to 43:

40 - G=0 K=0 Y=0
41 - G=1 K=0 Y=0
42 - G=2 K=0 Y=3
43 - G=2 K=0 Y=3

GRID SEQUENCE

The following command sequence is sent from the Model 595 over the IEEE-488 bus to cause the digital plotter to draw a grid:

```
IFC REN UNL MTA(0) LAG (5)
IN; PA; IP700, 800, 10050, 7500;   [INIT, P1, P2]
SP1                                [PEN]
SC0, 10, 0, 10;..draw..grid..lines..  [SCALE]
SI.13, .23; SC0, 100, 0, 100;      [ABSOLUTE CHAR
                                   SIZE-cm]
PU96, -3; LB..label..etx....send..
all..label..strings....
SI; PU85, -8; LBKEITHLEY 595
etx SPO;
```

PLOT SEQUENCE

The following command sequence is sent from the Model 595 over the IEEE-488 bus each time a data plot is started.

```
IFC REN UNL MTA(0) LAG(5)
IN; PA; IP700, 800, 10050, 7500;
SP1;
IW700, 800, 10050, 7500;
SC...send..scale..integers....
PU...send..first..data..point..integer...
PD...send..data..integers....
```

NOTES:

1. All numbers except SI are integers.
2. The HP 7470A Plotter has been verified to be compatible with the Model 595; in addition, the following plotters should also work with the instrument: 7090, 7475A, 7550A, 7580A, 7580B, 7585A, 7585B, 7586B.

KEITHLEY

Service Form

Model No. _____ **Serial No.** _____ **Date** _____

Name and Telephone No. _____

Company _____

List all control settings, describe problem and check boxes that apply to problem. _____

_____

_____

- ❑ Intermittent
- ❑ IEEE failure
- ❑ Front panel operational
- ❑ Analog output follows display
- ❑ Obvious problem on power-up
- ❑ All ranges or functions are bad
- ❑ Particular range or function bad; specify _____
- ❑ Batteries and fuses are OK
- ❑ Checked all cables

Display or output (check one)

- ❑ Drifts
- ❑ Unstable
- ❑ Overload
- ❑ Unable to zero
- ❑ Will not read applied input

- ❑ Calibration only
- ❑ Data required
- ❑ Certificate of calibration required

(attach any additional sheets as necessary)

Show a block diagram of your measurement system including all instruments connected (whether power is turned on or not). Also, describe signal source.

Where is the measurement being performed? (factory, controlled laboratory, out-of-doors, etc.)

_____

_____

What power line voltage is used? _____ Ambient temperature? _____ °F

Relative humidity? _____ Other? _____

Any additional information. (If special modifications have been made by the user, please describe.)

_____

_____

Be sure to include your name and phone number on this service form.

KEITHLEY

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Printed in the U.S.A.